Cross-Cultural Comparisons of Physical Activity; Observations from High-Income Countries and a Hunter-Gatherer Population

Luke David Willem Kretschmer

Thesis Submitted for the Degree of

Doctor of Philosophy

University College London

2023

Declaration

I, Luke David Willem Kretschmer, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

09/10/23

Abstract

Physical activity's impact on health throughout the life course is well-established, but low rates of activity, especially in childhood, persist. While previous studies have explored how activity correlates within and between populations, research on the full distribution of activity and its cross-cultural differences are limited. This thesis aims to integrate data and methods from epidemiology and biological anthropology to investigate the distribution of activity in high-income nations and a hunter-gatherer population.

Differences in the distribution of individuals was observed in the objective accelerometery data in the International Childrens Accelerometry Database (ICAD). In this dataset boys were more active on average, undertaking a greater average amount of moderate-to-vigorous physical activity (MVPA). However, the greater variation also observed for boys may imply that differences in average activity levels are not caused by all boys undertaking more activity, but a larger subset undertaking additional activity beyond 'day-to-day' activities. Between the contributing studies, more active populations were not necessarily more variable, but a study that was variable in one threshold of activity was likely to be variable in others.

Amongst the BaYaka hunter-gatherers, volumes of activity were over three times higher than World Health Organisation recommendations. Volumes of activity peaked in early adulthood but were high across the life course. Men were marginally more active, but differences did not appear to be driven by women's reproductive status or due to proximity to markets. Compared to the American National Health And Nutrition Examination Survey (NHANES) and British Millennium Cohort Study (MCS) datasets, activity increased with age across childhood, with boys and girls sharing similar activity levels. While BaYaka children appeared to show a regular pattern of activity across the day, they varied more between days than American school children.

This thesis provides new evidence to further an understanding of the socio-cultural determinants of health. It emphasises the role highly active hunter-gatherer societies can play in contrasting sedentary modern cultures. While gender and aged based differences in activity were the norm in the included high-income populations, the BaYaka differed notably, with high levels of activity that increased equitably with age for boy and girls. This thesis also demonstrates the value of developing a nuanced understanding of the full distribution of activity. Amongst the ICAD studies, statistically examining the variability and skewness furthered an understanding built solely on the mean.

Impact Statement

Despite its clear and established association with health outcomes, physical activity research to date often focusses on a narrow array of high-income cultures, with attention placed on factors that affect the average, rather than the full distribution. This thesis sets out important empirical, methodological, and theoretical contributions to the field of physical activity research.

In a hunting and gathering ecology that would better typify most of human history, the BaYaka help to demonstrate where contemporary high-income cultures may leave us susceptible to non-communicable diseases. In a high-quality objective account of physical activity in an understudied model of human evolution, the BaYaka engaged in three to six times the recommend minimum amounts of activity. This research highlights the importance of taking a broader approach to assessing cross-cultural differences. This is demonstrated by the gender divides that were consistent across the selection of high-income populations included in this thesis were not observed amongst the BaYaka. Further in ecologies that facilitate inactivity, children in the NHANES and ICAD datasets became less active with age, while an ecology that necessitates activity for the BaYaka was associated with increased activity with age.

Expanding on existing work examining inequality between groups, Generalised Additive Models of Location Shape and Scale (GAMLSS), an underutilised technique within the epidemiological sciences, allows for the inequality within a group to be examined simultaneously. Compared to typical regression techniques, this approach offers novel insights across the full distribution beyond just examining central tendency. Here, greater volumes of activity by boys were built upon greater inequality between individuals. This approach also demonstrated that populations that create a more equitable distribution of activity in one avenue, such as MVPA, were more equitable in all measures of activity.

To further disseminate this research, Chapter 3 has been published in the International Journal of Behaviour, Nutrition and Physical Activity, under the title Gender differences in the distribution of children's physical activity: evidence from nine countries. Chapter 6 is in preparation to be published. Additionally, the work from Chapters 5 and 6 have been presented at the European Human Behavioural and Evolution annual conference in both 2022 and 2023, as well as the International Society for Evolution, Medicine and Public Health in 2023.

UCL Research Paper Declaration Form

referencing the doctoral candidate's own published work(s)

Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:

- *have been uploaded to a preprint server*
- *are in submission to a peer-reviewed publication*
- *have been published in a peer-reviewed publication, e.g. journal, textbook.*

This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.

1. **For a research manuscript that has already been published** (if not yet published, please skip to section 2)

a) **What is the title of the manuscript?**

Gender differences in the distribution of children's physical activity: evidence from nine countries

b) **Please include a link to or doi for the work**

https://doi.org/10.1186/s12966-023-01496-0

c) **Where was the work published?**

International Journal of Behavioral Nutrition and Physical Activity

d) **Who published the work?** (e.g. OUP)

BMC Springer

e) **When was the work published?**

September 2023

f) **List the manuscript's authors in the order they appear on the publication**

Luke Kretschmer, Gul Deniz Salali, Lars Bo Andersen, Pedro C. Hallal, Kate Northstone, Luís B. Sardinha, Mark Dyble, David Bann & International Children's Accelerometry Database (ICAD) Collaborators

g) **Was the work peer reviewed?**

Yes

h) **Have you retained the copyright?**

Yes

i) **Was an earlier form of the manuscript uploaded to a preprint server?** (e.g. medRxiv). If 'Yes', please give a link or doi)

Yes - https://doi.org/10.1101/2023.04.17.23288558

If 'No', please seek permission from the relevant publisher and check the box next to the below statement:

☐

I acknowledge permission of the publisher named under ***1d*** *to include in this thesis portions of the publication named as included in* ***1c****.*

2. **For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)

a) **What is the current title of the manuscript?**

b) **Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv; if ‘Yes’, please give a link or doi)

Yes: https://www.biorxiv.org/content/10.1101/2023.11.29.569171v1.abstract

c) **Where is the work intended to be published?** (e.g. journal names)

d) **List the manuscript’s authors in the intended authorship order**

e) **Stage of publication** (e.g. in submission)

3. **For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4)

   LK, MD, GDS, and DB designed the research question and analysis plan, to which LBA, PH, KN, and LS provided critical input. LBA, PH, KN, and LS led original data acquisition. LK analysed the data and wrote the initial draft. All authors read and revised the manuscript and approved the final version.

4. **In which chapter(s) of your thesis can this material be found?**

   Chapter 3

5. **e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work)

Candidate

Luke Kretschmer

Date:

9/10/23

Supervisor/ Senior Author (where appropriate)

David Bann

Date

9/10/23

Acknowledgements

This thesis is a testament to my supervisors; Dr David Bann, Dr Gül Deniz Salali and Dr Mark Dyble. Your support and encouragement has kept me going over the last four years. Thank you, David, for being my mentor throughout this doctorate, your guidance has been invaluable through which you fostered my independence as a scientist. I'm so grateful to Deniz who, since meeting during my masters, allowed me to be a part of her research. If you hadn't sparked my interest in applying evolutionary principles to human health, I wouldn't have pursued a PhD in epidemiology. And to Mark, thank you for stepping in while Deniz was on maternity leave. Your fresh insight shaped the final form of this thesis.

Secondly, I would like to thank my funders at ESRC and BBSRC, and the board of the Soc-B Centre for Doctoral Training for letting this biological anthropologist onto an epidemiological PhD program. I am particularly grateful to all the participants that made this research possible, and I want to thank the teams behind the ICAD, MCS and NHANES dataset for putting together and maintaining these brilliant resources. I am indebted to the BaYaka community, who graciously shared their lives with us, granting their unique and invaluable perspective to this research.

Completing a PhD in a pandemic while keeping my sanity (largely) intact is thanks to a brilliant group of friends and colleagues. A special thanks goes to the past and present members of the 7th floor; namely Meg Arnot, Emma Walker, Charlotte Louise Campbell, Charis Bridger Staatz, Maddie Davies-Kellock, Sarah Stock, Jess Kurland and Katie Taylor. Your advice, support, friendship, and conversations kept me going over the past four years. I am also grateful to the Human Evolutionary Ecology Group who have provided feedback on my research throughout and kept my fascination with human evolution burning. I would also like to extend my deepest gratitude to my examiners Drs Esther Van Sluijs and Danny Longman who provided a brilliant discussion which helped to finalise the thesis.

To my parents, Judith and Ebb, I owe the deepest debt of gratitude. You developed a curiosity and love for learning in me that has propelled me as far as one can imagine. I am also deeply appreciative of my sister Ellen, who has been the steadfast friend every brother needs. Your constant presence and support have meant the world to me. To my friends Toby, Stefan, Adam, Will, Matt, Tom, Alex, and Jordan thank you for keeping me grounded, and to Matt, Riz, Ian, Chris, Fiona, and Graeme; thank you for keeping me moving. Thanks too go to Jayne and Charlie (Steve) for their ongoing and unending support.

Finally, a huge thank you goes to Roma, whose unwavering love has been a pillar of strength throughout this journey. Your support, guidance, and companionship have been invaluable. I look forward with great anticipation to what the future holds for us.

Contents

List of Tables

List of Figures

Abbreviations

WHO	World Health Organisation
NHANES	The US National Health And Nutrition Examination Survey
MCS	The UK Millennium Cohort
ICAD	The International Childrens Accelerometry Database
GAMLSS	Generalised Additive Models for Location Shape and Scale
GGIR	GENEActiv and GEANEA data in R
BMR	Basal Metabolic Rate - Also referred to as Resting Metabolic Rate or RMR
PAL	Physical Activity Level
MET	Metabolic Equivalents
MVPA	Moderate to Vigorous Physical Activity
MPA	Moderate Intensity Physical Activity
VPA	Vigorous Intensity Physical Activity
LPA	Light Intensity Physical Activity
cpm	Counts Per Minute
mg ENMO	Milli-gravitational Units, Euclidean Norm Minus One
MIMs	Monitor Independent Motion Sensing
NCD	Non-communicable disease

Chapter 1 Introduction

Physical activity is an established, modifiable health behaviour with a clear relationship with well-being.[1,2] Yet, despite the well documented benefits of an active lifestyle, there remains a global pandemic of physical inactivity. Per year, low physical activity has been attributed with 15.7 million disability-adjusted life years lost, and 832,000 deaths,[3,4] with an annual economic burden of inactivity estimated at $27 billion in 2022.[5] While physical activity impacts health across the lifespan, childhood appears to be an sensitive period for movement, and the one in which patterns of behaviour are formed.[6] Amongst contemporary high income populations there appears to be a consistent decline in physical activity levels throughout childhood, which persists into adulthood,[7] but volumes at all ages vary between nations.[7,8] This thesis attempts to address two limitations in the current research. Firstly, current approaches to examining cross-national patterns in child activity have focussed on measures of central tendency but have had limited sensitivity to analyse the full distribution of activity amongst a population. Secondly, cross-national research has had a limited cross-cultural perspective, particularly with populations outside of contemporary market economies. To further develop an evolutionary perspective on activity profiles, this thesis examines physical activity in a hunter-gatherer population, exploring how physical activity may have manifested in human evolutionary history and how this could help us to understand the health issues arising from a lack of activity.

This introductory chapter introduces the central themes and theories underlying the thesis. To begin with, an overview of what physical activity is and how physical activity influences health is provided, before introducing the current global state of physical activity, with a focus on children's activity profiles. From this epidemiological groundwork, an introduction to how evolutionary insights could aid an understanding of human health and physical activity is provided, with an emphasis on how hunter-gatherers may help to model the behaviours that typified human evolutionary history. This chapter concludes by introducing how these schools of thought can complement each other through cross-cultural research, with an overview of the limitations of research to date building into the aims of this thesis.

1.1 Epidemiological perspectives on physical activity.

1.1.1 What is physical activity?

Physical activity refers to any voluntary movement of the body that uses energy to contract and relax skeletal muscles.[9] Though commonly mis-conceptualised as activities undertaken in the pursuit of being 'physically active' such as leisure activities, physical activity includes any volitional movement of the body. As such, being physically active is found in walking to the shops as much as it is found going to the gym.

Physical activity has long been associated with health. Hippocrates (460-370 BCE) provides one of the earliest records of a doctor prescribing physical activity to a patient (a prescription for walking to a patient with tuberculosis).[10,11] Though the best form in which exercise should be undertaken is debated[12,13] (Hippocrates himself criticised his teacher Herodicus for recommending activities that he viewed as being too strenuous for his patients)[11] contemporary research largely contends that while different types of physical activity may differentially benefit different aspects of physiology and therefore health (with resistance training conferring a greater benefit to the muscular and skeletal system, while aerobic training may provide more of an improvement to cardiovascular function)[14] any improvements in overall activity levels are beneficial for health.[15] The benefits of an active life are well documented with a clear curvilinear dose-response relationship[1,2] including improved cardio-vascular function[16] with greater maximal oxygen uptake,[17] improved mental well-being,[18] better sleep,[19] and a reduced risk of severe COVID-19 outcomes[20] resulting in an increased life span and health span of active individuals.

Yet, despite these established benefits of an active lifestyle, post-industrial populations are rapidly coming to grips with a health crisis borne of an energy imbalance.[21] In 2022 the World Health Organisation (WHO) estimated that over a quarter of the global adult population fails to meet health guidelines for activity, with the rate twice as high in high-income nations compared to low-income (37% and 16% respectively).[5] Though recommendations are higher for youth, it is estimated that globally 80% of children and adolescents fail to meet physical activity guidelines, with rates of inactivity higher in girls than boys (85% and 76% respectively).[5]

Potentially explaining some of the decreased rates of physical activity is the decreased requirements for activity in post-industrial populations. Through both modern technologies (such as private transport)[22] and labour transitions (with manual labour increasingly replaced with sedentary labour),[23] the requirements for habitual, daily activity is reduced.[24,25] From an evolutionary perspective, in which selection favours reproduction over longevity,[26] conserving energy through being sedentary where possible may be adaptive.[24] For ancestral humans, who would have experienced periods of caloric restriction,[27] only expending the energy necessary for survival (such as through foraging, caring for kin, and maintaining social bonds), would maximise the residual energy available for reproduction.[24] An evolved pressure to conserve energy wherever possible, 'mismatched'[28] into a contemporary ecology where it is possible to be highly inactive may partially underlie why individuals are highly sedentary despite the health consequences of inactivity.[25]

1.1.2 Physical activity for health and development.

1.1.2.1 Mechanisms by which physical activity influences health and development.

Physical activity benefits health through a few pathways. First, is the development of the body in response to movement to better facilitate future activity. Physical activity is dependent on the contraction and relaxation of muscles, which in turn is dependent on a vascular network that delivers both oxygen and stored energy to the muscles and removes waste products. Engaging in physical activity encourages the development of these systems, leading to greater muscle development,[29] an improved vascular system[17] including both a greater lung capacity, and efficiency at which oxygen is delivered to the muscle.[30,31] Bone density has also been observed to increases in response to the stresses of repeated movements,[32,33] which can in turn reduced the risk of osteoporosis.[34,35] Increased volumes of physical activity have also been associated with improvements in motor control and balance in both children[36] and adults.[37]

Physical activity has also been associated with health outcomes distally related to movement. Physical activity appears to reduce the risk of numerous cancers including cancers of the bowel, breast, endometrium, prostate, testes, and lung.[38] For bowel cancer, the effect may operate through both the management of insulin and bile acid and the reduction in transit time of waste products through the bowel. Physical activity may also act to manage the production of sex hormones which may underlie the reduced rates of breast, testicular and prostate cancers. The risk of Type II diabetes may also be mitigated by activity.[39] Here, the turnover of glucose and storage in muscles reduces the rate of storage, and thus the need for insulin production, which may also increase insulin sensitivity.[39]

General inflammation appears to be attenuated by physical activity, which may reduce risk for outcomes associated with chronic inflammation or stress.[40] For adults who undertake activity, there appears to be a negative relationship between the level of activity and resting levels of known markers of inflammation: C-Reactive Protein (CRP), interleukin 6 (IL-6), and fibrinogen (Fg), but the relationship is less clear in children.[41] The proposed mechanism by which this occurs is through the physical activity induced cytokine response, in which skeletal muscle producing IL-6 acutely during exercise, which stimulates IL-1 and IL-10, both of which have a strong anti-inflammatory response.[42] While IL-6 is implicated in chronic low-grade inflammation, the acute production of IL-6 during exercise is proposed to aid cellular sensitivity to IL-6, which in turn may reduce the resting levels of IL-6 as less is needed to produce a response.[42] This is in addition to aforementioned improvements to the circulatory system which may help to remove inflammatory byproducts more efficiently from the blood stream.

Dementia risk is lower amongst those who are and remain physically active into older age.[43,44] Physical activity can aid the maintenance or development of grey matter areas as well as maintaining blood flow through the brains, mitigating the risk of small vessel disease related dementia.[44] Physical activity also appears to benefit mental health, but the mechanism is less clear.[45] In randomised control trials, aerobic exercise appears to benefit depressive and anxiety related conditions.[45] Increased neuroplasticity, as encouraged by the development of grey matter in response to movement, may underlie some of the effect on mental health.[45] Other benefits to mental health may operate through the reduction in chronic inflammation,[46] the role of intentional exercise training, due to affect regulation, cognitive control, goal setting and self-efficacy.[45] Finally, some benefits may also arise from exercise as part of a social group. Stevens et al., (2021) noted that individuals who partook in group exercise were less likely to report depressive symptoms owing to reduced loneliness.[47] Though the authors note that there could be positive selection as individuals with less depressive symptoms at baseline were more likely to be part of an exercise of sports group.

Though temporally removed from the mortality risks associated with a lack of physical activity, activity levels during childhood and adolescence have implications for health and development both in the short and long term. Amongst children, higher levels of physical activity have been associated with improved immune function and reduced susceptibility to infection.[48] In a small cross sectional study of children (n=61) increased physical activity was associated with a reduced number of recorded sick days.[49] Observational studies in school aged children have associated increased volumes of physical activity with reduced odds of hypertension,[29,50] lower IL-6,[51] decreased CRP,[50,52] reduced LDL-cholesterol,[50] triglycerides and blood glucose.[53,54]

Children observe similar benefits to mental health as adults do in response to physical activity.[29,55] Further increased physical activity has been associated with cognitive function in children.[55] In a review of intervention studies increased physical activity was positively associated outcomes directly tied to schooling (i.e. exam scores and language development) and indirectly (i.e. concentration).[56] Increased physical activity has been associated with motor control,[56] and increased muscular strength and muscular endurance in randomized trials.[53] A positive correlation between physical activity and bone density is seen in randomized control trials, longitudinal and cross-sectional studies.[53]

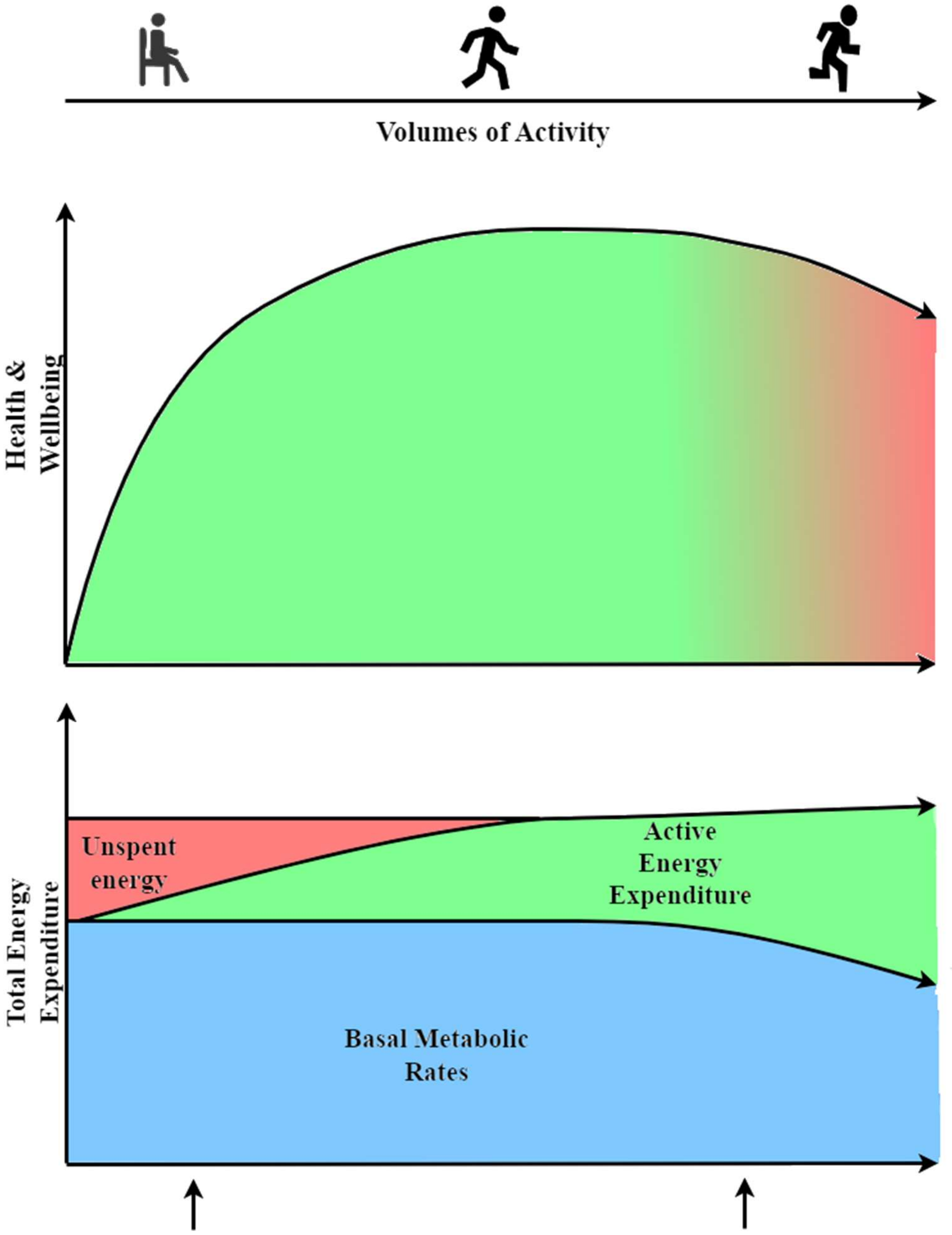
Beyond effects that are observed within childhood, physical activity in youth is tied to osteoporosis outcomes in later life,[34] with up to 60% of the risk explainable by the bone density accrued by early adulthood.[57] Though possibly a product of a lack of life long physical activity studies, present physical activity appears to have a stronger association with short term health outcomes compared to longer term outcomes.[58] Thus, activity in childhood may not have as much relevance to adult health as activity in adulthood.[58,59] Though an additional relevance to physical activity in childhood, is the association it bears with physical activity in later life.[58]

While most of the previously mentioned effects appear robust in randomised control trials,[9] some level of positive selection could influence the associations seen in cohort studies, namely that those with a lower risk of developing these conditions are more likely to remain active.[60–62] Included in this, individuals who develop muscle more readily, or have a more efficient vascular system may be more likely to become and remain active. The potential reverse causation has been argued by some, such that in observational studies, overall health influences an individual’s ability to be active.[63] Thus, the reduced risk of mortality predicts the capacity for activity, rather than activity predicting mortality. Equally there could be clustering of health behaviours, with individuals who remain active being less likely to smoke or consume alcohol.[64,65] While these can be accounted for in study design and in control trials, there may be residual confounding.

1.1.2.2 Modest increases in activity benefit health.

Physical activities' relationship with health appears to be curvilinear. For adults, for volumes of up to 300 minutes per week, there is a near linear inverse relationship between volumes of activity and mortality risk.[2] Above this volume, there seems to be no added benefit of additional activity, with a potential increase in mortality risk in activity volumes exceeding 400 minutes per week. However, even at 'extreme' levels of exercise, the relative mortality risk remains lower than wholly inactive individuals.[15] Further, at a population level, few individuals reach these levels of activity, as such, the confidence intervals around the relative mortality risk in extreme levels of activity are wide.[2] With very few individuals approaching this tipping point, increasing volumes of activity would likely confer health benefits to almost everyone.

The drivers of a potential increase in risk with very high levels of activity include overuse injuries, relative energy deficiency in sport (RED-S),[66] contact injuries,[67] risk of trips and falls,[29,68] and the increased risk of cardiac failure during sport (Figure 1-1).[15,69,70] Amongst children, some evidence supports a view that high levels of activity in youth can lead to delayed growth and maturation,[71] though this could also be a result of positive selection, with smaller individuals favoured in certain sports like gymnastics.[72] Countering a view of potential risks with extreme levels of activity is an observation of an increased life expectancy amongst a sample of 8,124 retired US Olympians, five years greater than the general population,[73] though these individuals are more likely to have come from affluent backgrounds than the general population.[74]



- Less excess energy.
- Development of cardio-vascular system
- Greater bone and muscle density
- Reduced inflammation
- Reduced hormonal profiles
- Reduced reactivity of the HPA axis
- Improved immune function

- Less energy available for basal functions
- Greater injury risk
- Lowered immune reactivity
- Further reduced hormonal profiles
- Dysmenorrhea and low sperm counts
- Risk of exercise-induced cardiac events

Figure 1-1: Modelled relationship between physical activity, health, and energy expenditure. Top panel highlights the curvilinear relationship between activity and health. Bottom panel highlights the differing components of total energy expenditure and how it varies with increasing active energy expenditure. Adapted from Pontzer (2018).[75]

1.1.2.3 Official recommendations for healthy physical activity.

Guideline volumes of physical activity have been recommended by the WHO and implemented as official guidelines in many countries.[76] For adults, the presently recommended amount of activity is 150 of moderate to vigorous physical activity minutes per week, or 30 minutes per day on at least 5 days of the week.[76] Public Health England described this intensity of activity as ‘enough to raise either the heartrate or breathing rate’.[77] This volume of activity was chosen as an amount that would bring a meaningful reduction in all-cause mortality yet be achievable for most individuals.[78] For children aged five to seventeen, the recommendation is 60 minutes of moderate to vigorous physical activity (MVPA) per day. For children less than 5, recommendations focus on all forms of activity not just moderate to vigorous activity.[6] From age 1, the recommendation is that children spend at least three hours in activity, which from three years old should include at least one hour of moderate-to-vigorous activity.

1.1.2.4 Are the benefits of physical activity just the benefits of reduced adiposity?

Physical activity has been viewed as reciprocal to diet in balancing energy and thus weight.[79] Put simply, the idea is that one side effects calories in, the other effects calories out. This view is not new either; in addition to recognising the value of activity, Hippocrates also noted that eating well and exercising possess opposing qualities that work together to produce ‘health’.[10,11] As a result, weight related conditions, including obesity, have long been viewed as a partial product of a lack of energy expenditure. Thus, some of the beneficial effects of physical activity on health were operationalised through a reduction in adiposity. While this is still debated, there is increasing consensus that there is not clear directionality from a lack of physical activity to weight gain.[80,81] Part of the confused bidirectionality is that it requires more energy (force) to move a larger mass to a similar acceleration, or, heavier individuals require more energy to generate as much movement as a lighter person.[82]

Some evidence goes further to propose that weight is what drives physical activity rather than the other way around.[83] A study of Danish children in the OPUS (Optimal well-being through School Meals) study observed that at a 9-month follow-up amongst children aged 8 to 11 years, physical activity could be predicted by baseline fat mass index but follow-up fat mass index could not be predicted from baseline physical activity.[84] A similar study in Norwegian 10 year olds with a 7 month follow up observed baseline adiposity measures to predict physical activity, but not the other way around.[83] Studies from Herman Pontzer’s Lab studying human energetics come to similar conclusions, putting forward a model of ‘constrained energy expenditure’, in which they note that in intervention studies targeting physical activity, the amount of additional energy spent above pre-intervention levels tails off with time, with the body adjusting the amount of energy dedicated to basal metabolic functions to ensure the total energy expenditure remains relatively stable (Figure 1-2). While this model is contested,[85] evidence does appear to support a view that in longer studies where the volume of activity is increased, the relative increase in total energy expenditure compared to baseline is negligible after six to ten weeks.[86]

Criticisms of the constrained model of energy expenditure include an over-reliance on cross-sectional (as in the case of the comparison in total energy expenditure between Hadza and US adults)[87] or correlational studies rather than randomised controlled trials.[85] Testing of compensation is largely conducted through null hypothesis testing (i.e. testing whether there is evidence to support the conclusion that two samples are different) rather than equivalence testing (i.e. testing whether there is evidence to support the conclusion that two samples are the same). Studies reporting a compensatory mechanism largely report total energy expenditure rather than using proxies for different avenues through which energy is being consumed (i.e. an accurate account of food stuffs consumed) and expended (such as using proxies for hormonal and immune markers in addition to measures of activity and total energy expenditure). Studies also largely ignore or dismiss the effect of adaptation to activity, such that there would be a non-linear relationship between increasing activity and energy expenditure as more trained individuals undertake activity more efficiently.[85] While some longer studies and animal studies have shown some degree of energy compensation, these have not reached complete energy compensation. On balance, the likely response to additional activity falls somewhere between the additive and constrained hypotheses. While more movement does cost additional energy it is offset to some degree but not wholly so, with potential increases in appetite compensating for any imbalance.[85,88] As such, despite all of the previously outlined benefits of physical activity, weight loss may not be one of them.

Additionally, the relationship between physical activity and health appears to be independent of adiposity.[80,89] Some evidence suggests that the mortality risk associated with obesity can either be attenuated or eliminated with sufficiently high volumes of physical activity, independent of any changes in weight.[89,90] Weight loss in itself does not appear to consistently benefit health,[91] and appears to be relatively unstable.[92] A study of over 3000 Americans estimated that amongst those who lost at least 10% of their weight, only 20% kept their weight off for at least one year.[93] Some studies have estimated that those who do weight cycle are at increased odds of mortality,[90] however, the results are inconsistent.[91]

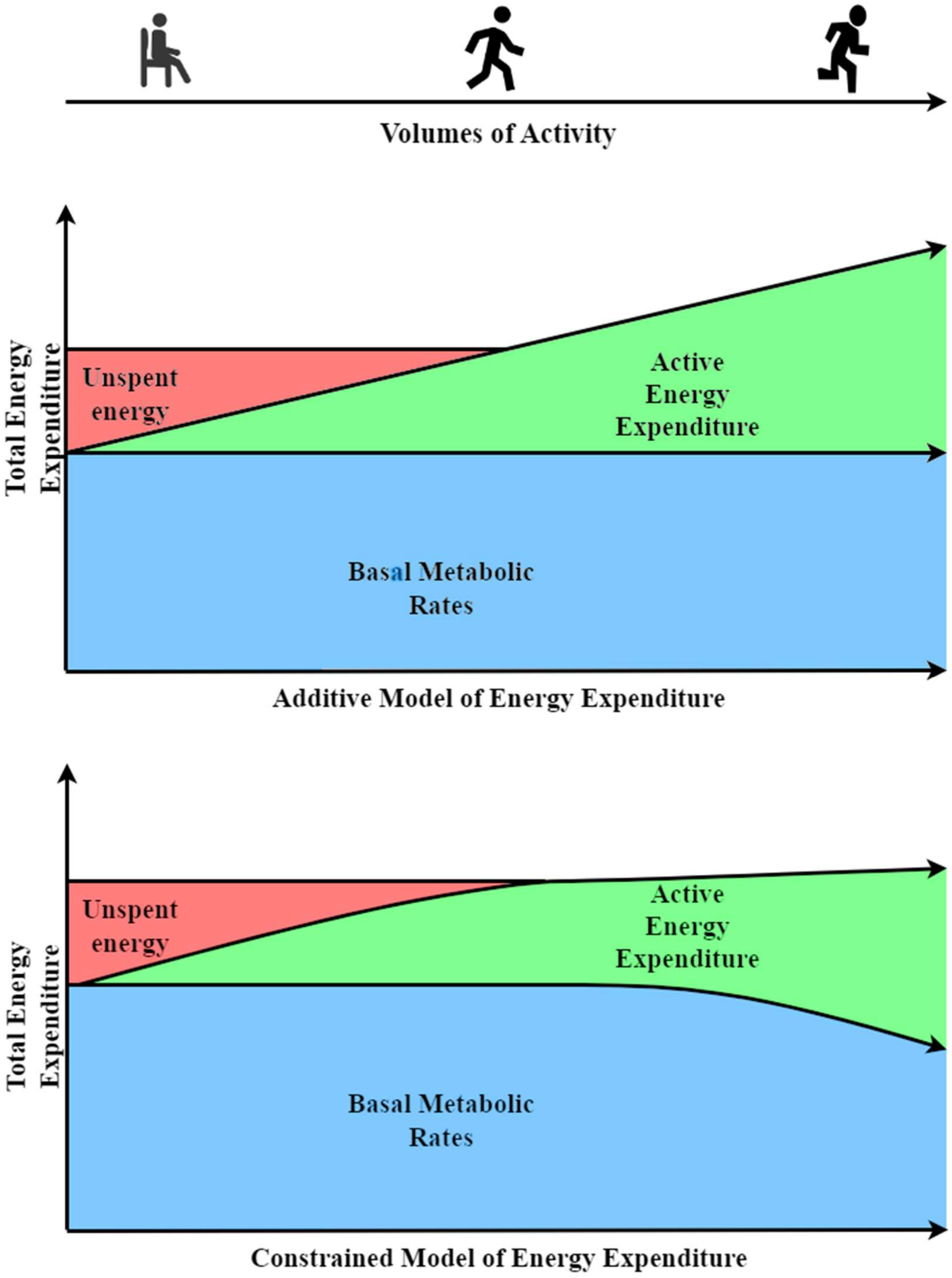


Figure 1-2: Simplified energy expenditure under additive and constrained models. Under an additive model, additional activity costs additional activity. In this model, if activity increases but intake of calories does not, individuals enter a calorie deficit, which may be compensated for by stored energy. Under an constrained model, total energy expenditure is limited. For an individual to spend more energy on movement, less must be spent on other functions.

1.1.3 The present state of global physical activity.

1.1.3.1 Trends in adult activity.

Globally, there is concern over the low levels of activity amongst adults and children. With recommendations set at 150 minutes of moderate-to-vigorous physical activity per week for adults, a 2012 review estimated that a third of adults globally failed to meet this threshold, with the rates highest of inactivity in the Americas and eastern Europe.[94] The same 2012 review estimated that in the UK almost two thirds of adults failed to meet the same threshold.[94] Updated in 2016, global proportions of inactivity remained relatively stable.[21] Though chosen for marketing reasons,[95] a target of 10,000 steps per day is often set as an activity benchmark.[96] Yet, in a study of 700,000 globally dispersed smart phones, the mean participant undertook less than 5,000 steps a day.[97] By this measure Japanese participants were amongst the most active with near to 6,000 steps per person, with European populations near the mean of 5,000, with the Americas and Middle East lower still. However, such a measure is dependent on both ownership of a mobile phone modern enough to have an accelerometer, and that individuals always had their phone on them.

Through the 20th and early 21st century the volumes of physical activity also appear to have fallen. While the volumes of leisure time physical activity may have increased, volumes of occupational activity have decreased.[94] Similar trends have been observed in the Tromso Study in Norway,[98] the Health Survey for England,[99] in Finland,[100] and Canada.[101] A study of American adults estimated that daily energy expenditure on activity has fallen by 100 calories over the past 50 years,[23] with estimates of cardiorespiratory fitness (measured by VO^2max) declining by 7.7% over the same time span.[102] Reframing an increased in activity, as introduced in section 1.1.1 and expanded upon in 1.2.2.3, a reduction in activity may also be viewed as the reciprocal outcome from an increased opportunity to be sedentary.

1.1.3.2 Trends of inactivity in children.

Like adults, children appear to show similarly low levels of activity, but estimates vary depending on the sample and methodology. Though activity recommendations are higher for children (60 minutes of MVPA per day), a review of self-reported activity levels estimated that 80% of adolescents globally are inactive, with girls consistently reporting less activity than boys.[94] Amongst children in the International Childrens Accelerometry Database (ICAD), the largest pooled dataset of children's accelerometry drawing largely from affluent nations, the mean child acquired 65min/day of moderate to vigorous activity, but with notable heterogeneity. US and Brazilian children recorded approximately 45min/day while Norwegian children exceeded 80min/day.[94] In a global meta-analysis of pre-schoolers, a third of the 20,000 children included undertook less than recommended amounts of activity.[103]

Further complicating the rates of childhood activity is the potential heterogeneity between individuals. Activity is acquired in many domains, which cross-nationally can influence how active children are, and how equally activity is shared between them. Where activity is embedded into daily life, through either the facilitation of activity, such as the cycle networks of Denmark, or a lack of infrastructure facilitating sedentary behaviour, like the underdeveloped car infrastructure of Nepal, activity appears to be higher across all individuals.[104] While countries like the US invest heavily in youth sport, without an active infrastructure, this benefits only those who undertake sport, leaving average activity levels in youth notably low.[94,104]

Though activity recommendations are consistent across childhood and adolescence, rates of inactivity do not appear to evenly spread across ages. In the ICAD, overall activity levels seem to increase up to ages 5 to 7, before declining consistently until age 18.[7,8] Volumes of MVPA, as undertaken in sport or active play, peak a couple years after overall activity, but show a similar decline with age from 9 through to 18 years.[8,105] Puberty has long been recognised as a turning point in activity, with early adolescence marking a decline in activity, particularly amongst girls,[106] which may be augmented by the transition from junior to senior school.[107] Objective measures, like those included in ICAD highlight that the decline begins earlier, at approximately the age that children move from play based to more formalised schooling.[7] In a study of Norwegian children, trends in activity across ages have remained relatively stable in studies between 2005 and 2018, with approximately 90% of six year olds, 80% of nine year olds, and 50% of fifteen year olds meeting the recommended volumes of activity.[108]

Little research has documented how volumes of childhood activity have varied across time. Like adults, there appears to potential decline in overall activity with time, but a potential increase in the amount of sport and leisure undertaken. Drawing on objective activity data from Denmark, Sweden and the Czech Republic, a 2015 review estimated that overall levels of activity have been relatively constant across the past 20 years.[109] Whereas a study using self-reported measures observed a general increase in organised sports participation but a consistent decline in active transport across a sample of

European and English-speaking countries over a similar time period.[109] A study of Norwegian children observed no meaningful change in activity levels between 2005 and 2018, with a trend of decreasing activity with age present in all the included waves (2005, 2011 and 2018).[108] A review of activity in sub-Saharan school children did not observe a discernible trend in activity with time, but did observe decreasing activity in areas that have experienced urbanisation.[110]

1.1.3.3 Gendered disparities in activity

Amongst both youth and adult samples, gender is frequently observed to be a correlate of physical activity. In youth studies, boys frequently record more activity than girls across childhood and adolescence.[111,112] While the WHO estimates that 81% of children and adolescents fail to meet health targets, the percentage of girls is higher at 85%.[5] Similar observations are made amongst adults with men often undertaking more activity than women.[5] Though the guideline daily amounts for adults are approximately half that of children and adolescents, 23% of men and 32% of women are insufficiently active.[113] Both boys and men are more likely to report engaging in sport or leisure activities,[114] while men are also more likely to have a physically active occupation.[115]

In a cross-sectional study of self-reported physical activity in adolescence including 347,935 individuals across 52 countries, a gender disparity was observed with boys undertaking vigorous activity on one day more per week than girls.[116] The difference was most pronounced when exploring activities outside of school compared to activity undertaken within school, which could be taken to indicate that a difference in activity is driven by leisure-time exercise rather than activity of daily life.[a] Compounding this difference, the study drew from self-reported activity, which may be biased towards more memorable activities, like sport and leisure.[117,118] As such, where there is a gender divide in sports participation, the difference in self-reported activity may be exaggerated. In a small study (N=25) of Brazilian children, the scale of difference between the genders differed notably between objective and subjective measures.[119] By self-reported data,

[a] Here and through-out the thesis, 'activity of daily life' or 'lifestyle activity' are used to refer to movement acquired in a behaviour that an individual has little individual control over, such as activity conducted as part of the structured school day, domestic activities, and transportation. 'Leisure-time activity' is used to describe activity aquired through an individual's freely disposable time, including any sport or active play that is not a part of a structured curriculum.

compared to girls, boys undertook an extra 250 minutes per week of MVPA, but with accelerometery this disparity shrank to 105 minutes per week. Indicating, that when less memorable 'everyday' activities are included, the difference between boys and girls narrows.

Despite a potentially reduced disparity, accelerometery still frequently observes a difference between boys and girls. The IDEFICS study, a cross-sectional, cross-national study of accelerometry data from 7684 children across a selection of 8 European nations, observed the proportion of youth meeting health guidelines of MVPA (60min/day) to vary between the genders, with boys more likely to meet targets. However, both the proportion of individuals meeting guidelines, and the magnitude of difference between the genders differed between the nations.[120] Discussed further in section 2.1.2, in a multinational subset of 24,316 individuals in the International Childrens Accelerometry database at all ages boys undertook more MVPA than girls.

Some evidence has further suggested that the difference in activity is found in all intensities of activity. In a cross-sectional study of 9-to-10 year old children's objectively measured physical activity in three UK cities (London, Birmingham, Leicester), in addition to differences in MVPA (Boys = 70min, Girls = 60min), compared to girls, boys were observed to engage in more light activity.[50] Though statistically significant, this amounted to a near meaningless difference of six minutes (Boys = 181min, Girls = 175min). Though this may imply that boys are more active across the full spectrum, rather than just those associated with sport and active play, it does imply that it is the most intensive activities that meaningfully differentiate boys and girls. With increased overall volumes of activity amongst boys, time spent sedentary should offset these increases. Matching these predictions, within the ICAD dataset, boys spent less time in sedentary thresholds at all ages.[7]

Amongst adults, a review of reviews found that of seven reviews that reported gender as a possible determinant of physical activity, two found strong support for men having higher physical activity with none of the remainder finding the inverse.[121] Another review found similar trends with two of six finding an association with men engaging in more MVPA.[122] As with youth samples, self-reported measures of activity often exceed objective measures, which may again bias differences in favour of men, due to the increased recollection of leisure and occupational activity, but an underreporting of lifestyle activities.

With physical activities relationship with health, the consistent divide between genders paints a poor picture for equality in health outcomes. The disparity in activity may contribute to some of the gendered differences in particular disease outcomes. A review of outcomes in 13 European or English speaking nations observed women to be more likely to be diagnosed with obesity, depression and arthritis, with the later augmented by age-related declines in estrogen production.[123] Though these results may be biased owing to their reliance on self-reported diagnoses, similar results are seen in studies of Indonesian[124] and Iranian[125] adults.

While a gender disparity in activity appears across multiple study populations it appears to be partially driven by consistently gendered leisure and occupational activity. Despite gendered behaviours in many hunter-gatherer,[79,126] pastoralist[127] and horticulturalist[128] populations, these do not appear to lead to differing levels of total physical activity when using an objective measure.[126,129–131] Indicating that despite specialised foraging undertaken by each gender,[132] such as men hunting with women gathering[79], the net physical activity output is seemingly comparable. Accordingly, in understanding determinants in gendered activity profiles, cross-cultural studies can help elucidate which factors may be more readily modifiable.

1.2 Evolutionary perspectives on physical activity.

Evolution can be used to help understand why individuals act the way they do. Evolutionary sciences look to examine how selection has shaped individuals to maximise their fitness. Compared to epidemiology, the fittest individual in an evolutionary sense is not necessarily the one who has the longest or healthiest life, but the one who leaves the most copies of their genes in the next generation, either through their own offspring or that of their kin.[133] Beyond morphology, evolution shapes the behaviour of individuals, influencing how, when and why individuals act as they do in a bid to maximise their fitness. With movement being a central part of human behaviour, an understanding of physical activity can be enhanced through the lens of evolution. Drawing on life history theory and evolutionary energetics, physical activity and the energy it requires can be viewed as part of a dynamic system of energy allocation.[24] With the added relevance of activity to wellbeing, evolutionary medicine aims to provide a model of ‘health’ informed by evolution, with a perspective on why individuals may or may not act in a way that maximises their health.[26]

1.2.1 Introducing evolutionary medicine.

Combining evolutionary and epidemiological perspectives, the field of evolutionary medicine explores human health through an understanding of evolutionary constraints, trade-offs and mismatches.[25,26] By incorporating evolutionary theory, this approach attempts to expand upon the proximate mechanisms of how people get sick to address why people get sick.[26] The evolutionary perspective of health operates on the premise that:

I. Selection looks to maximise reproduction, not health. A trait that improves health but worsens reproductive returns will not be positively selected for.
II. All organisms balance a series of trade-offs to maximise reproduction given their ecology. Maximising one trait will likely cost another.
III. Evolution cannot select for a trait that is not already present in the population, thus, while many traits show plasticity, phenotypes are constrained by evolutionary history.
IV. Evolution occurs over generations, for a long-lived species like humans it is a slow process. Through cumulative culture human environments can change faster than human genomes, especially in modern post-industrial contexts. This can leave genes adapted for an environment in which they do not reside, therefore mismatched with their environment.[25]

In the case of physical activity, with an understanding of the mechanisms of how physical inactivity leads to disease outcomes, an evolutionary approach attempts to address what life history trade-offs may explain why individuals are active or inactive and how this impacts health outcomes. Within this is, focus is placed on exploring how modern culture, which differs from the lifestyle that most human evolutionary history is characterised by, leaves individuals mismatched with their environment and thus susceptible to illness.[134,135]

1.2.2 Life history theory and evolutionary energetics.

1.2.2.1 An overview of life history theory.

With energy being the central currency of life, life history theory contends that individuals should balance their investment of energy to maximise their evolutionary fitness.[133] Energy can be invested in numerous ways; into growth and development, into repairing damage to the body, developing and deploying an immune response, into having and rearing offspring, and into movement.[136] Importantly, each joule of energy can only be spent once, so investing energy into one process means it is no longer available for another.[137] Characterised as the fast/slow continuum, individuals and species vary in how they allocate energy to maximise their fitness, either by investing quantity, quality, or a strategy in-between.[138]

Characterised by the strategy of mice, a fast life history aims to reach maturity quickly, and to maximise the rate of reproduction once mature, without investing too heavily in any given offspring as there is a high risk of mortality for all individuals. [138] As such, a fast life strategy looks to maximise quantity at the expense of quality. At the other end of the spectrum, is a slow life strategy. Typified by elephants, when individuals have a higher chance of surviving into reproductive adulthood, reproductive gains are made by maximising their reproductive competitiveness in adulthood. A slow strategy therefore looks to invest more in developing and maintaining their bodies, and those of their offspring.

As between species, individuals should also balance how they invest their energy to maximise their reproductive fitness.[139,140] In an ecology of high mortality, investing too heavily in growth if there is a low chance of surviving to reproductive adulthood would be ill advised. Instead, fitness returns would be higher if an individual prioritised reaching maturity at a younger age. Observed amongst the Western Central African hunter-gatherer populations, a proposed response to high rates of mortality is the reduced adult stature traded-off for an earlier age at maturity compared to other African hunter-gatherer groups.[141] Alternatively, if individuals have a high probability of surviving in adulthood, failing to invest in growth and development compared to their contemporaries may restrict their reproductive opportunities in adulthood.

1.2.2.2 Trade-off in energy expenditure across the life course.

To enact varying strategies, energy is differentially invested into growth, reproduction and maintenance, which further respond to the developmental stage across the life course.[142,143] For humans, childhood is characterised by growth and development as individuals progress toward reproductive maturity. Once reproductive maturity is met in adulthood, the focus transitions to maximising reproduction, with energy less dedicated to growth, shifting instead toward maintaining that earlier investment, and supporting any children.

For most of human history, until the advent of modern medicine and an understanding of infections, childhood was a period of high mortality[144] and it remains so for contemporary hunter-gatherers and other populations with limited health care access.[145] As such, in addition to investment in growth and development,[146,147] to aid survival into adulthood large amounts of energy is invested into developing and maintaining an immune response.[148] The trade-offs in these energetic demands can be seen in the Tsimane of Bolivia, who live in a high pathogen environment.[149] For children (2months - 8years old) greater investment in adaptive immune function (measured via white blood cell counts) was associated with lower height for age.

Trade-offs in energy investment continue into adulthood. Though growth is largely completed, and mortality is at its lowest,[145] this period of life is focussed on reproduction. The form of investment varies between the sexes with unequal pressures on energy allocation beyond anisogamy, i.e. the differing costs of producing eggs compared to sperm.[150] For females, reproduction includes the additional energetic costs of gestation and lactation.[151] As both influence offspring survival, and thus reproductive success, investment in both should be highly conserved.[152,153] While men do not bear the same energetic costs, reproductive fitness is still dependent on the number of kin that survive into adulthood to produce their own offspring. To do so, men can either look to invest in producing more offspring, or to invest more heavily in fewer offspring to aid their reproductive fitness.[154–156] As such, men can look to either increase the care and calories they provide to offspring and mother, or look to leverage more reproductive opportunities.

1.2.2.3 Balancing energy budgets.

With these trade-offs, individuals should look to maximise the pool of energy available for investment. One method to increase the available energy for growth and reproduction is to increase the total energy intake, something that has only become possible year round with modern agricultural industrialisation.[157] Where increasing the intake is not possible, the alternative is to decrease output. One major consciously modifiable output of energy is physical activity, it accounts for up to a third of all energy expenditure[137] with being sedentary offering an energy saving of approximately three times that of being moderately active.[87] In an ecology of finite resources, physical activity should occupy an optimum that maximizes the energy available for other processes, without compromising the ability to obtain the necessary resources for survival and reproduction. Post-industrial populations have largely moved away from calorically constrained ecologies and therefore face less restriction in increasing their intake of calories to match their expenditure. Additionally, physical activity may also be decreasingly required to access these resources, as seen in the transition away from occupational labour.[94]

Complicating this, the constrained energy budget hypothesis contends that individuals can only expend a certain amount of energy each day.[75] If an individual were to increase the amount of energy they spend on movement, the body would compensate for this and reduce expenditure elsewhere (Figure 1-2). Such a model of energy budgets may explain the observed lack of association between physical activity and weight, as increasing the amount of energy spent on movement is compensated via basal metabolic functions rather than stored energy.[81] Observed in extended physical activity interventions, after a period of time (6-10 weeks) individuals adjust to their new levels of activity, and their total expenditure falls back toward the pre-intervention levels, despite a greater amount of energy being dedicated to movement.[86]

With the view of movement trading off basal functions regardless of the nutritional status of the individual, the amount of energy spent on movement should respond to the developmental stage and condition of the individual.[158] For children, activity should be at its lowest in early childhood, when large portions of energy are being put toward growth, development, and immune function. Across childhood, activity should increase as the rate of investment in growth and immune function decreases, and with development the capacity for movement may also increase. Transitioning toward reproductive maturity requires energy, first in the development of the reproductive system, then through its maintenance. While this manifests in adolescence, the transition begins in late childhood.

For females, physical activity should peak after puberty (when the investment in growth and development is slowing) but prior to the energetic costs of reproduction (through pregnancy and lactation). Initiation of reproduction should suppress physical activity, and it should remain low whenever the energetic costs of gestation and lactation arise throughout reproductive adulthood. As women more often exit puberty before men,[159] their peak in physical activity may come before men. Without the energetic costs of gestation or lactation, and with the incentive of greater provisioning, men physical activity should peak during their reproductive adult years.

From the perspective of physical activity being part of a dynamic system of energy allocation, some of the indirect benefits of physical activity can be seen (See section 1.1.2.1 for an examination of the proximate mechanisms). Energy spent on physical activity cannot be used for other processes, including the chronic production of sex steroids implicated in the link between physical activity and cancer.[75] Hadza men, a hunter-gatherers of Tanzania, appear to have low resting levels of testosterone,[87] which may be due to the relative energetic cost of producing sex steroids.[160] Amongst Tsimane forager-horticulturalists of Bolivia and Hadza hunter-gatherers, a one standard deviation increase in testosterone was associated with an extra 175kcal/day of energy expenditure.[160] Similarly, male endurance athletes often observe lower resting testosterone levels,[161] while female athletes report reduced oestrogen and progesterone,[162] which in extreme situations can lead to amenorrhea.[66] Immune responses may be blunted, requiring a higher threshold for activation, reducing the risk of a chronic, low grade inflammatory response.[75] Taken to the extreme for individuals who partake in very high volumes of activity, the suppression of their immune system can increase their risk of infections.[66] Similarly blunted responses are proposed to underlie the reduced chronic cortisol levels of the physically active.[75] While cortisol spikes during activity, this is associated with reduced reactivity of the HPA axis at rest, limiting the chronic production of cortisol.[163] This combined effect to suppress chronic inflammation may contribute to a number of beneficial health outcomes,[40] with all of the above cumulatively resulting in the added life expectancy of the physically active.[164,165]

Complicating these trade-offs with other functions is that the energetic costs of activity are also traded off with the fitness benefits derived from being physically active. For hunter gatherers and other subsistence populations, amongst other functions, physical activity is employed in the pursuit of foraging for calories, in caring for kin, and maintaining social networks, all of which positively influence evolutionary fitness. This fitness return on activity can be short term as in the case of foraging, or longer term, as in the case of skill building in youth,[166] or through investment into social networks.

1.2.3 Hunter-gatherers as a model of evolutionary health.

Prior to the advent of agriculture 12 thousand years ago (kya) human subsistence was based on what was directly forageable from their environment.[167] While humans have been subject to selection since the Neolithic Revolution (arguably the most notable of which is lactase persistence),[168] humans have adapted for a life of hunting and gathering. With the earliest fossil of *Homo sapiens* dated to 180kya, with the wider *Homo* genus's fossil record dated back to an earliest appearance 2.3 million years ago (mya), most of human history has been defined by a hunting and gathering lifestyle.[169,170] With selection occurring at a generational scale (assuming a 25 year generation) to the present day the genus *Homo* has experienced 92,000 generations, of which *H.sapiens* occupies the last 7,200 generations, with only 480 generations since the advent of agriculture. Termed 'mismatch' and 'diseases of civilisation', an examination of how modern ecologies differ from the hunting and gathering 'environment of evolutionary adaptedness' (or EEA) and how this has left us susceptible to disease, is a growing area of study.[25] Within this, a particular focus is on how this transition has left humans susceptible to numerous non-communicable diseases, and why they manifest in post-industrial populations so often.[25]

While humans display developmental and phenotypic plasticity in adapting to increases in activity within their lifetime[171] (as seen in studies of exercise interventions)[172] much of the last six million years since the last common ancestor with chimpanzee's and bonobo's has been shaped in the context of highly active lifestyles.[170,173,174] Natural selection would therefore have occurred within and in favour of bodies that could effectively handle larger volumes of activity.[175] Unlike modern day great apes, ancestral hominids likely resided on the fringes of forests and grasslands, and it is in this environment that the initial adaptions to bipedality would have occurred.[176] While multiple explanations have been put forward to explain this transition, some likely adaptive benefits include greater locomotor efficiency and heat management when covering longer distances in more open terrain.[175–179] Transitioning from frugivores to opportunistic omnivores, such adaptations may have allowed early humans to find scavengable carcasses in open terrain before larger predators[175] (Ancestral humans have been estimated to be the 9th ranked predator in the paleoguild and would be have been displaced and actively predated by larger carnivores including sabertoothed cats).[180] Within this context, selection would likely have favoured bodies that could travel longer distances more efficiently.[175]

Though estimates of exact activity profiles are difficult to infer from skeletal remains, the collection of ancestral traits absent amongst chimpanzee's and bonobos highlight selection in favour of elevated activity levels amongst hominids. Features including a narrowed and rotated hip, elongated leg bones, an arched foot, nuchal ligament that stabilises the head, as well as increased bone density in the femur highlight that ancestral humans put strain on the musculoskeletal system, for which selection favoured bodies that could handle this strain.[173] Compared to extant chimpanzees, modern-day humans walk approximately 20% quicker than chimpanzees at four times greater efficiency, with reduced muscle mass that is largely allocated to the lower limbs.[174,175,181] While humans have experienced selection in a broad swathe of ways that differentiates them from their closest living relatives that are not directly related to physical activity, they have all occurred within the backdrop of highly active lives.

Yet, while all extant humans share this active ancestry, differing exposures within a lifetime can alter the expression of traits associated with activity.[182,183] Termed phenotypic plasticity, two individuals with the same genotype can have differing phenotypes due to epigenetics (factors that alter what genes are expressed and to what degree).[171] Taking musculature as an example, the density of which responds to the level of use such that individuals who spend more time stressing their muscular system may develop greater muscle.[182] Underpinning this is that musculature is energetically expensive to build and maintain.[182] As such, individuals should only develop the musculature required for their daily activities.

While sports persons can act as a proxy for adaptation to highly active lifestyles, any adaptation is particular to their sport of choice. To understand the health impacts of an ancestral active, the palaeontological and archaeological record can provide some insight into historic human behaviour, but it is limited by the breadth of what has been preserved and what has been uncovered. An alternative is to study populations that still engage in modes of subsistence similar to those before the Neolithic Revolution. Though hunter-gatherer populations should not be thought of as living fossils, as they have also experienced over 10,000 years of selective pressures since the Neolithic Revolution, they remain the closest contemporary approximation of behaviour in a Paleolithic ecology.[143,157,167] As such, they arguably offer the best available approximation of an evolutionarily informed model of health and the associated behaviours in a living population.[157]

Contemporary hunter-gatherers, like pre-historic populations, largely function as immediate return societies, in that acquired goods are used and consumed rather than stored, cultivated or accumulated.[184] Though their behavioural and cultural traits vary to suit their ecology, modern hunter-gatherers have a diet dependent on wild foods that can be hunted, fished, foraged or gathered, and they operate in small and mobile units that move locations dependent on the availability of these resources.[157,184,185] Diets reflect locally available food stuffs and vary spatially and seasonally.[186,187] Unlike the diets portrayed in pop-science 'paleo' diets, hunter-gatherer diets are often high in plant products and carbohydrates, with the 'high protein, high fat, high animal product' diets promoted by paleo diet supporters only observed in high latitude populations like the Inuit of the North American Arctic for whom there is little plant growth.[186,187] Additionally, very few extant populations still exist on pure hunting and gathering, and many will supplement their diet with cultivated goods when the trading opportunities arise.[188,189]

Broadly, extant hunter-gatherers are egalitarian; no one individual has a defining say over the actions of others.[190] Though there is variation, individuals are largely monogamous, partially owing to the inability to acquire wealth.[190] Groups follow a fission-fusion residence pattern, with family units moving between locations and groups as needed.[190] Most hunter-gatherers show a gendered division of labour with men more often targeting less reliable but larger returns through a focus on larger game.[191] Women more often target readily forageable goods including plant products and smaller game, but there is substantial variation between groups, and in most men will forage and women will hunt.[192] Referred to as immediate return subsistence populations, there is limited ability to store food, so all acquired food is consumed soon after collection. This drives the food sharing seen in hunter-gatherer groups between unrelated individuals. As seen in vampire bats,[193] where it is not possible to otherwise store calories, it is best to store them in your peers who can return the favour later.[191] Groups are largely co-operative, engaging in foraging efforts together, distributing food returns and collectively caring for children. Kin selection cannot fully explain the high level of co-operation, as due to men and women having equal influence over their residence group, the average relatedness of groups is typically lower than neighbouring small scale non hunter-gatherer groups.[190]

There are limitations to the use of contemporary hunter-gatherers to model ancestral behavioural patterns. Among which is the recognition that contemporary foragers are as temporarily removed from the ancestral populations as the proposed mismatched contemporary post-industrial populations are.[143] While their overarching mode of subsistence amongst extant hunter-gatherers bears a resemblance to the ecological pressures experienced by ancestral populations, there has been a similar amount of time for innovation and adaptation.[157] For the BaYaka included in this thesis, but true for many extant hunter-gatherers, contemporary foraging and navigating the forest has benefited from newer technologies including machetes and shotguns.[166] Trade with local farmers has broadened their diet, as it can be supplemented with cultivated goods, as well as alcohol and tobacco.[189,194] Though dependent on the forest for survival, the establishment of near-by fixed settlements has increased access to health care and education.[188] As such, contemporary hunter-gatherers cannot perfectly reflect the behavioural suite of palaeolithic populations.[143] However, the similarity in mode of subsistence, and the broader life history trade-off required means they likely mirror ancestral populations better than any other extant free-living population.

1.2.3.1 A hunter-gatherer childhood.

Childhood represents an extended period in which individuals can grow, develop and learn.[195] Compared to other apes, for our size humans experience a relatively short gestation but an extended childhood.[196] A proposed selective force behind this is that due to the variety and complexity of human's cultural ecologies, spending more time developing outside of the womb allows children the plasticity to develop in their social niche.[197] Being born relatively early and altricial means less of our behavioural responses are fixed, with the extended pre-adult period offering the necessary time to acquire the cultural corpus of information.

Hunter-gatherers are culturally diverse with childhoods that reflect that diversity but with some consistent pressures. Early infancy is similar across most cultures with infants developing the cognitive and motorneuronal skills that other apes are born with, developing both the ability to navigate their environment and communicate with others.[198] Amongst which includes the time taken to learn and develop language skills, develop gross and fine motor control (i.e. both ability to walk and to manipulate tools) as well as the necessary cognitive and socio-emotional skills.[199]

Transitioning into middle childhood, (ages 5-11 years) the focus moves toward the cultural knowledge needed for survival in their individual niche.[196] This involves both the development of skills (such as how to build traps for BaYaka hunter-gatherers of Congo-Brazzaville) as well as the social connections and friendships needed.[196,200] While this transition is mirrored in post-industrial populations through the transition in education style; moving from play based learning to a more formalised classroom setting.[201] For hunter-gatherers, childhood is marked by large volumes of play, typically spent in mixed gender, mixed age play groups.[200] This serves to both foster the social relationships necessary for the co-operative hunting and gathering niche, and with play modelling adult behaviours, starting to build the skills needed for adulthood.[202] Children will also engage in food production, often targeting easy to acquire foods, with self-provisioning making up 10-50% of their daily calories during early and middle childhood, with the volume increasing with age as skills and strength develop.[203] Children will also undertake domestic work and care for other children, as well as partaking in or play-modelling cultural and spiritual activities,[204] but the largest allocation of time is to play.[205]

While on average hunter-gatherers reach their peak levels of foraging skill in their early thirties (as measured by daily calorie returns)[206] focussed development of foraging skills begin in earnest in the teenage years.[205] During adolescence children start to spend less time in play, with more time in adult-like behaviours, with a focus on developing the skills needed for their niche.[166,205] Unlike post-industrial children who move away from play-based learning at ages 5 to 7 years,[201] hunter gatherers continue to primarily learn through play until early adolescence.[200] While play would often model adult behaviours, this transition sees the early shift toward increasing the calorie return of foraging. For the BaYaka, focussing on skill development begins with being led and instructed by adults or older adolescents, with age individuals will start to lead these foraging efforts, before a final transition to teaching younger children the same skills.[166]

Sexual maturity is also reached during this phase, but often occurs at a later age than in post-industrial populations. Typically, girls will reach sexual maturity, as marked by menarche, at around age 15, but can be as late as 18 as seen in the Gainj and Asai of Papua New Guinea.[207] Though contemporary post-industrial populations observe average menarcheal ages of 12 to 13,[208] during the mid-19th century in the USA and Europe the average reported age was closer to that observed in hunter-gatherers, being estimated at approximately 16 to 17 years.[209]

The availability of energy likely underlies some of the transition to earlier maturity seen in post-industrial populations, and the lack of change in hunter-gatherers.[210,211] With growth and development being energetically costly, the ability to invest in maturation is a function of both energy intake and energy expenditure. Post-industrial populations have seen an increase in the amount of available calories, which with increased processing are easier to extract,[212,213] while simultaneously observing a decline in overall activity levels.[100,102] For hunter-gatherer children, foods often require large amounts of processing to be edible, with plant products remaining high in fibre, reducing the amount calories digested[189] with activity likely unchanged.

1.2.3.2 Hunter-gatherer health.

Though susceptible to infectious illness, this mode of living appears to have left hunter-gatherers with very low rates of non-communicable diseases,[157] the primary cause of death in high-income nations.[214] Amongst studied populations, this includes a higher VO^{2}max, lower rates of metabolic disorders including obesity and (Type II) diabetes, lower average blood pressures and blood cholesterols (Table 1-1). Additional work is ongoing to further discern the rates of cancer and neurodegenerative disorders which appear to occur at a lower rate in subsistence populations but are harder to ascertain in field sites without developed medical equipment and practitioners.[157]

Table 1-1: Compiled comaprative measures of cardio-respiratory and metabolic health in subsistence and post-industrial populations.

	SUBSISTENCE POPULATIONS	**POST-INDUSTRIAL POPULATION**
VO^{2}MAX	50 mlO2 kg−1 min−1 (Eskimo and San) [135]	38 mlO2 kg−1 min−1 (German Men, Aged 20-40) [215]
BLOOD PRESSURE	119/74 mmHg (Tsimane, Aged 60+)[216]	136/74 mmHg (British Adults, Aged 60-79)[217]
CHOLESTEROL	115 mg dL^{-1} – Hadza[157] 153 mg dL^{-1} - Tsimane[216]	220 mg dL^{-1} - England[218]
BODY MASS INDEX (BMI)	20.2 kg/m^2 – Hadza (Aged 20-80)[157] 24 kg/m^2 – Tsimane [127]	27.6 kg/m^2 - England (Aged 16+)[218]
RATE OF CLINICAL OBESITY (BMI > 30)	0.5% - Hadza[157] 3% - Tsimane[127]	28% - England (Aged 16+)[218]
RATE OF TYPE II DIABETES	1% - Multiple[135] <1% - Hadza[157] <1% Tsimane[216]	7% - England (Aged 16+)[218]

Though hunter-gatherer life expectancy at birth is lower than populations in developed countries, much of this is attributable to a high level of child mortality.[145] In a study of 5 hunter-gatherer populations, for individuals surviving to age 15, the estimated modal age of death was 72 with the major causes of death at all ages being acute infection, injury and accident.[145]

Focus is often placed on comparing hunter-gatherers to inactive industrialised populations as a means of understanding health outcomes in developed nations. While modern health trends draw on the ideals of "*ancestral*" hunter-gatherer behaviour[219,220] few rely on quantitative methodologies. Those that do often use a summary measure from a developed country to make these comparisons. Work by Raichlen et al.(2017)[130] explored the difference between Hadza physical activity and that of industrialised populations including an American sample taken from the NHANES study in the USA. However, these comparisons are made using summary statistics drawn from other studies, in this case namely the work of Tucker et al.(2011)[221] and Dugas et al.(2011 & 2014)[222,223]. The issue in these comparisons is a lack of control over the methodology employed, from the mode of recording, data processing and choice of reported statistics. Thus, the values reported cannot be reliably compared.

Amongst the identified literature pertaining to hunter-gatherer physical activity (Table S C-1), only one study contrasting between populations using an objective measure of physical activity. In Sayre et al.'s (2020)[224] contrast of the Hadza Hunter-Gatherers and Pokot Pastoralists they highlight the similarity in levels of MVPA between the populations. Though Hadza showed no effect of gender on physical activity, within the Pokot a gender difference was observed with women having a lower mean acceleration, but not a corresponding reduction in the amount of MVPA. The explanation put forward for this is that food production, which is typified by walking large distances herding cattle, is dominated by men. Amongst the Pokot, women's activity is centred around household maintenance, which while still active, may explain the lower mean acceleration. The directionality of the gender difference here mirrors that of the Huli[225] with the increase in market integration reducing women's physical activity but not men's, as daily activities from farming to domestic work for women but to active wage labour for men.

1.2.3.3 The physically active lives of contemporary hunter-gatherers.

With a daily routine including foraging, socialising, maintaining camp and caring for others, a hunting and gathering lifestyle appears to be very active. [127]A study of the Hadza, a group of hunter-gatherers from northern Tanzania, estimated that their daily volumes of MVPA exceeded 2 hours per day, a value 14 times higher than American adults in the 2005-6 NHANES study.[130] Detailed further in Chapter 5, most studies of subsistence populations observe volumes in excess of the 150min/week WHO guidelines.

Despite the raised levels of activity, hunter-gatherers appear to expend similar total amounts of energy per day. A study of energy expenditure in the Hadza estimated that adjusted for fat free mass, Hadza adults spent similar amounts of energy to sex-matched American adults.[79] The implication is that Hadza adults must make savings in other avenues of energy expenditure to balance the total energy expenditure given the increased energetic investment in physical activity.[79] Reducing the energy available for basal processes has been proposed to be a mechanism via which physical activity improves health as less energy is then available to produce excess sex steroids or to produce an inflammatory response, both of which are implicated in the relationship between physical activity and health.[86,158] Given the reduced energy of basal metabolic functions,[79] a drive to conserve energy where possible could therefore be adaptive for a small-scale subsistence population as this would leave more energy to invest into growth, maintenance, and reproduction. As such, it may be expected that hunter-gatherers should be as inactive as possible.

Fittingly, hunter-gatherers do appear to spend large volumes of time spent sedentary, with estimates in the Hadza of up 10 hours of the wakeful day being spent in sedentary thresholds of activity,[131] similar to volumes observed in post-industrial populations.[2,226] However, compared to the sedentary time observed in post-industrial populations (seated with the back supported, or reclined), the sedentary postures for Hadza adults includes squatting, kneeling, or sitting without back support, typically on the ground.[131] It has been proposed that these periods of 'active rest' involve more muscle activation, potentially reducing the proposed independent effect of sedentary activity on health observed in adults[131,227] and children.[228]

Owing to both the limited number of extant hunter-gatherers and the number of research groups studying their activity and energetics, physical activity research in hunter-gatherers has been limited in its scope and scale. Notably, there is little research detailing children's activity levels in hunter-gatherer societies. A study of space-use in Baka children of Cameroon using waist-worn accelerometers observed children to undertake over 20,000 steps a day, with daily distances increasing with age.[129] Another, based on observational data, estimated an increase in moderate and vigorous intensity activity with age amongst Hadza children.[229]

Additionally, research has focussed on individual thresholds of activity rather than the full distribution across all intensities of activity. As the length of a day is finite, if an individual engages in more of one physical activity intensity this must be offset with a reduction in another.[230] Studies that find an association between an outcome and increasing the volume of an intensity threshold, such as MVPA, without including other thresholds may be misattributing the beneficial effect of reducing another behaviour.[231]

1.3 Cross-cultural approaches to physical activity research.

A large body of epidemiology looks to explore how health related outcomes and determinants are distributed throughout a population. Cross-national research looks to augment this by examining how the determinants and outcomes of health vary between populations.[232] The core idea is that by studying within a population, factors that vary within that population can be examined, but there is little sensitivity to examine factors that are ubiquitous within that population. For instance, a study in the UK examining the relationship of schooling and health outcomes can examine how factors associated with education affect health outcomes, whether that be the length of time in education, the level of school funding, or proximity to the school. But, because most children receive formal schooling, the role of schooling in itself cannot be examined. Cross-national studies therefore allow for an examination in variation between nations that may not be visible within nations.

In this way, cross-national studies have been used to highlight the modifying factors underlying disease outcomes, including the role of cholesterol in heart disease,[233] the heterogeneity in adolescent mental health,[234] the role of development and urbanisation in auto-immune disorders including asthma [235] and why rates of Covid-19 may have varied between nations.[236]

1.3.1 Understanding variation within and between populations.

While multinational datasets including the ICAD and PISA (Programme for International Student Assessment) have been used to compare youth physical activity between nations, methods have largely focussed on measures of central tendency.[7,116] While useful, there are additional avenues of differentiation between samples that remain underexplored, such as examining the degree of heterogeneity or evenness of spread.[237] It could be that two nations with broadly similar mean volumes of youth activity have notably different distributions, unseen by typical regression methods. For instance, a population with a larger inequality in activity, where some individuals have a lot of access to sport and leisure, with the remainder of the population having very little access to activity, might have a similar mean volume of activity to a more homogenous moderately active population. Measuring the central tendency would have less sensitivity to capture the difference between these two populations, despite differences in the distribution.

Though such an approach is underutilised,[238] understanding the spread of individuals could help to better understand between gender differences in activity and the possible reasons for this. For instance, two populations with different mean activity levels can have similar numbers of individual in 'healthy' thresholds due to differing variations, as illustrated in Figure 1-3. In Figure 1-3A, both distributions have 25% of the sample exceed the current WHO targets for children[76] of 60 minutes of activity per day, yet the means differ between the positively skewed sample ($\bar{x}$ = 35.6) and the normally distributed sample ($\bar{x}$ = 48.4) Conversely two populations with the same mean activity levels but different variance may have different volumes of individuals below activity thresholds. In Figure 1-3B, both samples observe the same mean volume of activity ($\bar{x}$ = 45), but the percentage of individuals exceeding 60 minutes varies between the skewed (32%) and normally distributed (15%) samples.

With physical activity being an upstream predictor of later health, it makes a good candidate for preventative interventions. Conceptualised as Rose’s two principal approaches to public health, understanding both the differences between groups as well as the differences within groups may help inform whether targeted or population wide approaches are more likely to have a better cost/benefit ratio.[239–241] With the non-linear relationship between physical activity and health,[2] there may be more benefit to public health per unit of investment by increasing activity amongst the lowly active a moderate amount rather than increasing activity for all individuals a small amount.[242,243] For two populations, such as Figure 1-3b, interventions targeted at the inactive subgroup in the skewed distribution (orange) may yield greater net benefits to health than it would in the normally distributed population (blue). However, these two approaches are not mutually exclusive. For example, population-wide approaches may be particularly effective in the most inactive groups in the population.

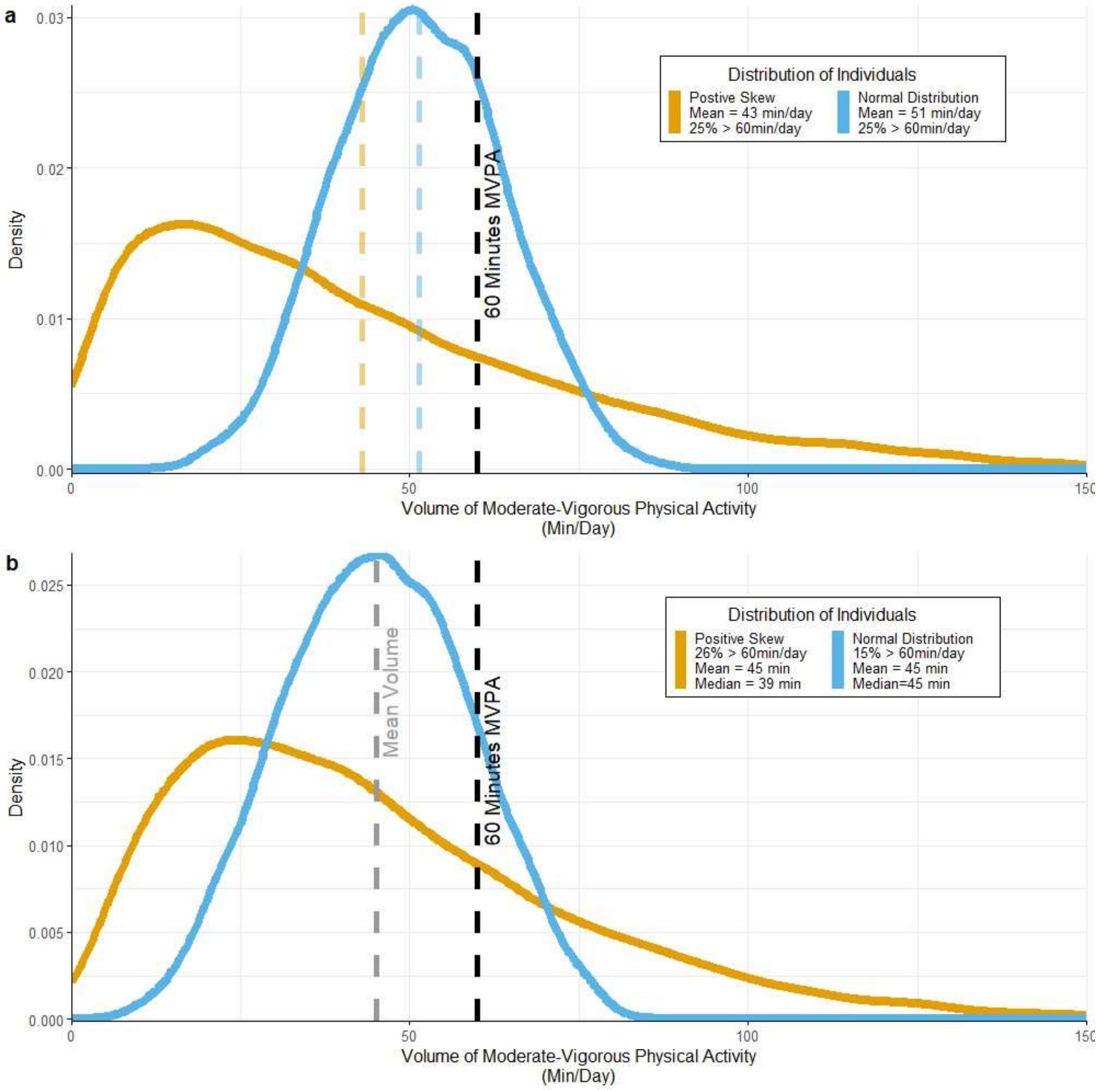


Figure 1-3: A: Two simulated distributions for which 25% of individuals in each distribution are above the threshold of 60min/day of MVPA, but mean values vary. Dashed vertical coloured line represents the mean for each distribution. B: Two simulated distributions for which the mean volume of activity is 45mins/day, resulting in varying proportions of individuals who reach the 60 min/day target for physical activity.

1.3.2 Adding more cultures to cross-cultural comparisons.

In addition to heterogeneity within populations, a further limitation in existing research is the limited variation between nations. With increasing globalisation, there is decreasing cultural variation, particularly amongst the affluent nations that form the majority of epidemiological research.[244] Marked in evolutionary literature by the acronym WEIRD (Western, Educated, Industrialised, Rich and Democratic),[245] the European and English speaking nations that make up the majority of epidemiological research[246] share similar cultures due to both their history (including their cultural ancestry and as colonial powers) and proximity, reducing both the variation and independence between nations.[247] There is a long-standing issue with a lack of representation of populations from the global south, and while efforts are being made to address the imbalance, a comparative lack of research in low and middle income countries exists.[246]

Thus, there is some need to expand the exploration of cultures outside of the traditional cross-national narrative to derive new insights into health outcomes and to examine those resulting from industrialisation.[25] While this includes more work with countries in the process of industrialisation, including many in the global south, there is further need to research the health and wellbeing of populations and cultures less effected by globalisation. One avenue to increase the level of contrast in both the underlying factors and the health outcomes is to compare populations and cultures with differing modes of subsistence, including those that still operate as hunter-gatherers. As hunter-gatherers appear to have low rates of non-communicable diseases, the primary cause of death in post-industrial nations, to understand the behavioural factors associated with the burden of non-communicable diseases, comparative hunter-gatherers studies may be insightful.[4,157]

Some comparisons between hunter-gatherer health and those observed in post-industrial populations have been made (See Table 1-1). Within the context of physical activity, Hadza adults have been estimated to undertake 14 times more MVPA than American adults[130] despite no difference in daily energy expenditures (adjusted for mass) between Hadza hunter-gatherers and a population sample of US adults.[79] However, to date there has been little research explicitly comparing the activity of hunter-gatherers to post-industrial populations, with many of those that do relying on summary measures from post-industrial populations. A further limitation of this is that few of these including enough children to explicitly examine the differences in childhood.

1.4 Aims and structure of the thesis.

Broadly, the central aim of this thesis is to investigate how physical activity varies within and between populations, broadly focussing on how the active lives of children is culturally variable. Within this this thesis seeks to address:

1. Within the multinational ICAD sample, how do gendered socio-cultural perspectives toward activity amongst boys and girls manifest throughout the full distribution of activity?
2. Expanding on socio-cultural differences within studies, how does the nation of study affect the distribution of activity amongst children?
3. Amongst the BaYaka hunter-gatherers, does physical activity differ between demographic groups in adulthood and childhood?
4. How does physical activity amongst BaYaka hunter-gatherers differ to high-income populations?

This thesis looks to draw new insights from existing datasets using underutilised methods to examine the variation between groups, and to contrast well studied populations with those underexplored in typical epidemiological research.

Chapter 3 and Chapter 4 draw from the International Childrens Accelerometry Database (ICAD) and employ currently underutilised Generalised Additive Models of Location Shape and Scale (GAMLSS) to expand upon differences in the mean between groups, to include differences in the distribution including the deviation and skew. Chapter 3 expands on existing research to examine differing distributions in activity between boys and girls, while Chapter 4 examines the differences in the distribution between the contributing studies within ICAD.

Chapter 5 and Chapter 6 concern the activity patterns of the BaYaka hunter-gatherers of Congo-Brazzaville. Chapter 5 predominantly focusses on adult patterns of activity, including analyses examining the role of gender, reproductive status, market integration and age on patterns of activity. Returning to the same population, Chapter 6 focuses on the activity patterns of BaYaka children and thus how the adult patterns of activity in Chapter 5 manifest through childhood. In doing so, analyses of how their physical activity varies between ages and genders across childhood and adolescence are undertaken, in addition to comparisons with studies from post-industrial populations, centring on the US NHANES study and the British Millenium Cohort Study.

Chapter 2 Introducing the datasets and methods employed in measuring physical activity.

This chapter introduces the populations and datasets included in this thesis, focussing on primary data collected with the Mbendjele BaYaka of Congo-Brazzaville, and secondary data from the International Children's Accelerometry Database (ICAD). An overview of the methods and techniques of quantifying physical activity are discussed. While data analysed in this thesis comes from accelerometry, numerous techniques have been used to capture and quantify physical activity. Introduction to these various approaches is provided to add necessary context to the literature discussed within the thesis. Finally, a broad introduction to the statistical methods used throughout the thesis is provided.

2.1 An introduction to the datasets employed in this thesis.

2.1.1 The Mbendjele BaYaka.

2.1.1.1 BaYaka subsistence and culture.

The BaYaka are a hunter-gatherer population that reside in the Congo rainforests of west and central Africa. The BaYaka include a wider collection of Western Central African subsistence populations including the Aka, Baka, Mbendjele, with the Eastern populations grouped under the term Mbuti.[248] Historically these groups have collectively been referred to as 'African pygmy populations'[249] owing to their comparatively small stature. However, this language should be avoided due to the derogatory nature of the term.

Genetically, Central African hunter-gatherer populations share a common ancestor, splitting from wider Bantu speaking populations between 50 to 70 thousand years ago.[248,249] Eastern and Western Central African groups diverged approximately 20 thousands years ago, with a common ancestor for Western Central African subsistence populations dated to approximately three thousand years ago. Assessments of language trees come to similar orders of events, with a division from wider Bantu languages preceding the divergence of eastern and western groups, with subdivides in western groups emerging more recently.[249] As a subgroup of the BaYaka, the Mbendjele are defined by their use of the Mbendjele language.[250] Estimates of the size of the population vary widely, with individuals spread between Cameroon, Gabon, Congo Brazzaville, the Central African Republic and the Democratic Republic of Congo with very few official records.[251] Lewis (2015) estimates a population of 15-20,000 Mbendjele,[250] Bahuchet et al., (2012) estimated numbers to be at least 60,000 for the Mbendjele and Aka,[249] with an estimate for all central African groups at almost 1 million individuals.[251]

The present thesis works with a group of Mbendjele BaYaka from Congo-Brazzaville residing in the Sangha River Basin in the north of the country (Figure 2-1). This group share much of their subsistence style with the broader Mbendjele and BaYaka groups. Subsistence activities in the BaYaka have been subdivided into five main categories: the hunting of large animals, the gathering of honey and hunting of invertebrates and other small animals, the collection of plants, fishing, and cultivating goods, but there is notable heterogeneity between groups and across the year.[252] While the BaYaka predominantly subsist on foraged forest products, groups differ in how much of their subsistence is based on foraging and in how much reliance there is on cultivated or market goods.[194]

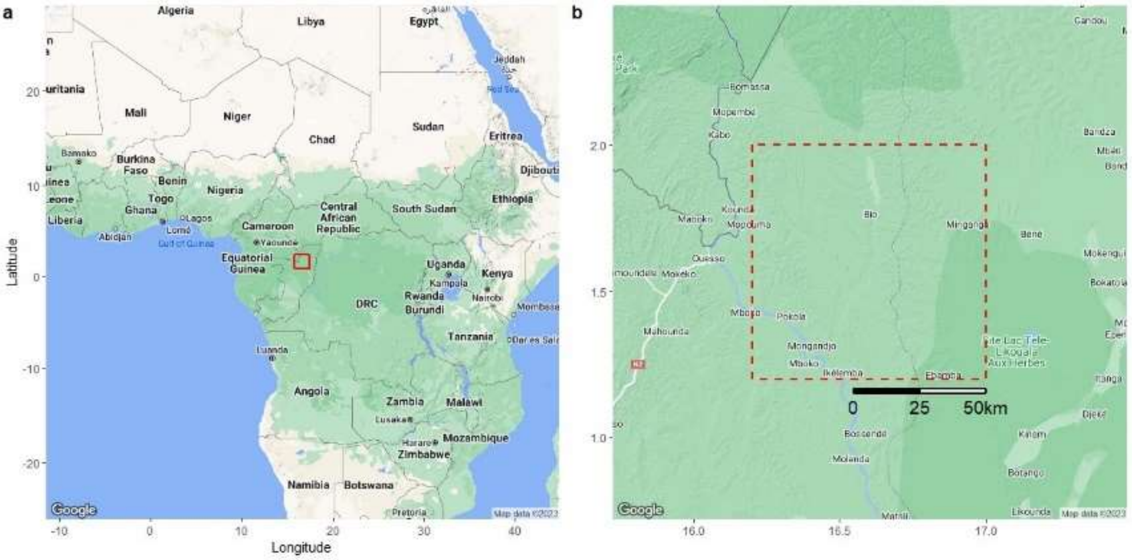


Figure 2-1: Location of the field site in Congo-Brazzaville. Panel (a) highlights the broader study area in northern Congo-Brazzaville. The solid red box marks the boundary of panel (b). Panel (b) highlights the field site, with data collection carried out within the dashed box. Research was centred on Pokola and the forests to the northeast of the town.

Ethnographic and field observations of the BaYaka suggest that they do exhibit a division of labour between men and women but there is overlap in activities, with women undertaking subsistence activities typical of men and vice versa depending on the relative availability of resources.[200,252] The hunting of large game and collection of honey is typically undertaken by men, with women predominantly focus on plant goods, caterpillars and other invertebrates and fishing.[252] Children often engage in foraging efforts at a level that reflects their skill, experience and strength.[200,253]

There is seasonal availability to the forageable goods driven by annual rainfall patterns. The dry season typically runs from December through to February, with the wet season occupying March to November, but rainfall can vary. The dry season is associated with more activity from bees, favouring honey collection, and lower river levels can make fishing easier during this period.[252] Whereas the wet season is associated with increased plant growth and invertebrates activity, favouring caterpillar collection.[252] Owing to the proximity to the equator, there are minimal variations in temperature throughout the year in Congo-Brazzaville.

This subsistence diet is often supplemented with cultivated and traded goods. BaYaka will trade forest products, for agricultural products, clothing, cigarettes and alcohol.[194] There is variation in access to trading opportunities, with those living closer to settlements having greater access to markets, with access for those living deeper in the forest dependent on passing farmers or traders on forest tracks and logging roads, or by travelling to fixed settlements. Accordingly, many of the forest camps are located in close proximity to the meandering logging roads that are spreading throughout the forest.[194]

Like other hunter-gatherer populations, the BaYaka are broadly egalitarian, with no formalised hierarchy.[250] The BaYaka are predominantly immediate-return foragers, meaning that any food acquired is consumed soon after, with little ability to store food, which acts to reduce the ability to accumulate wealth. Instead, with fluctuations in calorie returns between days and seasons and little ability to store surpluses, food returns are shared between individuals residing together. The BaYaka follow a fission-fusion residence pattern, with family units joining into and separating from larger groups at their own discretion. Typically, a camp will consist of up to 60 individuals, formed of multiple family groups,[190] but the semi-sedentary camps that form around towns can number in excess of 200 individuals.[188]

2.1.1.2 A BaYaka childhood.

Childhood represents an prolonged period of growth and development, the extended length compared to other apes has been proposed to be an evolved feature to allow necessary time to develop complex skills needed for life in the hunting and gathering niche.[195(p. 2)] For the BaYaka, this involves developing expertise in hunting and trapping animals, building dams in rivers to fish from, collecting honey, locating edible and medicinal plants, as well as developing the social relationships needed for survival.[166,200,253]

Learning and developing these skills begins at an early age, with the modes of learning varying with age before expertise is reached in adulthood.[166,206] In infancy children will start by imitating other individuals, by middle childhood, play becoming an important means of modelling adult behaviours with other children in mixed aged groups.[166] Throughout childhood, children contribute to foraging efforts, with their relative contribution increasing with age.[200] In times of plenty they will help adults to collect forageable goods, such as helping to fish during the dry season, and collect caterpillars during the wet season. Additionally children, but most often girls, will also take on domestic and childcare duties for the younger infants.[200,254] As children move through adolescence they start to spend more time foraging and in productive behaviours, and with increasing efficiency.[166,206]

BaYaka children are treated as autonomous individuals. Children are free to pick the activities they engage in, with a socially enforced norm that adults do not coerce children.[255] Reflecting a mode of "co-operative autonomy",[255] children do play an important and increasing role in their families subsistence, but are treated as independent decision makers, able to choose whether they cooperate or not. Boyette and Lew-Levy (2020) recount an occasion where a mother hit her child to stop him playing in a rubbish pile, following which the mother's mother-in-law and sister-in-law came to hit her (though done playfully) while scolding her for hitting her child to attempt to control his behaviour.[256]

2.1.1.3 Data collection amongst the BaYaka.

Data was collected during two field trips, the first in the July and August of 2018, the second in February of 2022. Both field trips were carried out in Likouala region of Congo's Ndoki swamp forest and centred on the town of Pokola in the north of Congo-Brazzaville. Sitting on the banks of the river Sangha, a tributary of the river Congo, the town has grown over the last 20 years with the expansion of the logging industry in the area and the employment opportunities it affords.[257]

During the 2018 trip to the field, three campsites in the Sangha River basin were visited by Gül Deniz Salali and Nikhil Chaudhury. The first campsite was on the outskirts of Pokola, the second approximately 45km into the rainforest, with the third a further 30km into the forest, with the latter two accessible via logging roads that stretched into the forest. In 2022, one camp was visited, but owing to the foraging opportunities during the dry season in the early months of the year, the Mbendjele had moved further into the forest due to the fishing opportunities. In 2018 data was collected between July and August, falling during the wet season and encompassing the caterpillar foraging season.

On both field trips, physical activity data was collected using GeneActiv devices amongst consenting participants; these are small, triaxial devices that resemble wristwatches. Prior to starting, individuals were advised on how to wear the devices, that they should do so on their non-dominant wrist, and that they should wear them continuously. While there is limited supported for outputs differing by choice of wrist, wearing the device on the non-dominant arm is typical practice when using wrist-worn accelerometers.[118] Differences in the study aims between the two field trips lead to differing recording lengths. In 2018, the research aimed to capture physical activity data across all ages of Mbendjele, thus individuals of all ages were included. With limitations due to a restricted number of devices (24 GENEActivs) and the time in each campsite, allowing for the change over time including downloading the data and recharging the devices, individuals wore the device for a minimum of 24 hours. In 2018, a total of 152 BaYaka wore a device.

While the 2018 collection focussed on providing a broad overview of the wider population, the 2022 field visit focussed on children. Here the aim was to provide a more detailed account of a narrower section of BaYaka society. Following approval from the children, their families and the wider community, children wore the accelerometers for 7 consecutive days, with everyone beginning and ending the recording on the same day. By capturing multiple days of activity for each individual, the amount of variability between days could be assessed. Studies of between-day variability have been undertaken in post-industrial populations, but no identified work has replicated this in hunter-gatherer populations. Additionally, a longer period of recording allows for the distribution of activity within a day to be assessed. In addition to being a child, the inclusion criteria were that they had to be responsible for their own movement (i.e. not carried) and able to wear the device, as such, the resultant ages ranged from 3 to 18. In 2022, a total of 24 BaYaka children wore a device.

In both field trips, physical activity data was collected in addition to a wider suite of information, with a selection of which included in this thesis. In both field trips age was taken from known ages where possible. For those that did not know their age, estimated ages using Diekmann's Bayesian estimation using relative age ranks was used.[258] This method asks participants to rank individuals they know by age. This is repeated across multiple individuals, and combined with either known ages or investigator estimates of potential age ranges in a Gibbs sampling Markov chain Monte Carlo algorithm. This produces a probability distribution for each individual's age, the mean of which is taken to represent their age. The need for an age estimates rather than direct recall is due to formal recording of births not being common practice amongst the BaYaka, and when it is done it is mostly amongst those near to fixed settlements. As such, BaYaka do not always have an accurate recollection of their age, especially as they get older. However, they more readily have a recall of who is older than who, allowing age ranks to be developed. Amongst the children included there is better recall of exact ages, and a greater ability to rank who is older and younger than them due to both finer developmental differences between individuals, and less time for estimates to drift. The 2018 data collection included all available BaYaka, which lead to greater confidence intervals around age estimates, as such, estimated ages were put into approximate age groups of children (aged 3-16), young adults (16-25), middle adults (25-50) and older adults (ages 50+). In 2022, physical activity data collection centred on children, for whom recalled or estimated ages were more accurately available, allowing age to be used as a continuous variable for this group. Gender was also recorded in both field visits based on self-report and observation. Within this study sample, individuals' sex and gender was aligned. In both chapters, data from babies (aged 0-2) were excluded as due to being carried often, any acceleration of the device could not confidently be attributed to them.

In 2018, additional variables included are pregnancy status (self-report and observation), breast feeding (self-report and observation), height (stadiometer), weight (portable scales), whether they had recently been sick (self-report), the village in which they resided, as well as information regarding the physical activity recording (i.e. when devices were given and collected back). In 2022, only covariates pertaining to age and gender were collected.

With this PhD beginning in 2020, the 2018 data collection was carried out prior to the involvement of Luke Kretschmer. The methodology for the 2022 accelerometery data collection was planned in collaboration between Luke Kretschmer and Gül Deniz Salali and carried out by the latter. The research and fieldworks were approved by the Ethics Committee of University College London (UCL Ethics codes 3086/003. Informed consent was obtained from all participants, their families (in the case of children) and the wider community. Prior to which individuals were briefed on what the devices were, what data they record and how to wear the device. For storage, each individual's data was anonymised and kept in line with GDPR guidelines. Research permissions were granted by the Republic of Congo's Ministry of Scientific Research. Data collection was led by Gül Deniz Salali and Nikhil Chaudhury, supported by BaYaka field assistants Nicolas Yuppe and Dambo Gaston; with Selcen Kucukustel, Sarai Keestra, Inez Derkx and Gaurav Sikka aided in data collection; while Dr Edmond Sylvestre Miabangana, Dr Laure Stella Ghoma Linguissi and Dr Guy Moussavou helped in acquiring the necessary research permits.

2.1.2 The International Childrens Accelerometry Database.

The International Children's Accelerometry Database (ICAD) is a free dataset used on licence from the data holders (MRC Cambridge) containing accelerometer and covariate data from globally dispersed children.[259] The aim of ICAD is to provide a harmonised dataset of accelerometry from multiple studies from across the globe. To do so, numerous groups contributed the raw data from their studies, to be reprocessed with a consistent methodology, adjusting for any changes in technology between the studies. This means that the activity estimates from multiple studies can be directly compared reducing the need to caveat that the interpretation of 'physical activity' may vary between studies as any methodological limitations are broadly similar across studies.

The studies included in ICAD were undertaken at different points of time and were not individually designed to be included in a harmonised multinational dataset. As such, while the data is processed in a consistent manner, it was not recorded as such. With time, both the methodologies and technologies used have changed, meaning that the conceptualisation of physical activity within these studies has also changed. Across the studies included in ICAD the device placement was consistent, but the frequency of recording improved with time. As it is impossible to add more resolution to the older devices, the approach taken was to reduce the resolution of the newer devices. In the case of ICAD this involves reducing triaxial recordings to uniaxial recordings on the vertical axis and adjusting the epoch to 60 seconds.

2.1.2.1 Harmonised datasets within the International Childrens Accelerometry Database.

Overall, the ICAD includes activity data from 37827 participants (n=14,232 boys, n=22,803 girls and n=792 with gender unknown) aged between 2.5 and 19.5. In the present thesis a subset of these individuals are used (n= 15,461). The selection of studies to include was based on the inclusion of individuals aged between 5 and 18, that the studies were either cross-sectional or the first wave of a longitudinal study of accelerometry, and were not primarily focussed on an intervention group.

The included studies were the Pelotas Birth Cohort (Brazil), National Health and Nutrition Examination Survey (NHANES) (USA), the Avon Longitudinal Study of Parents and Children (ALSPAC) (UK), European Youth Heart Study (EYHS) (Denmark, Estonia, Norway and Portugal), the Kinder-Sportstudie (KISS) (Switzerland) and the Healthy Eating and Play Study (HEAPS)/ Children Living in Active Neighbourhoods Project (CLAN) (Australia) (Table 2-1).

Table 2-1: Summary of studies included in ICAD that are used in this thesis. Number of participants is presented prior to data reduction (See Figure S A-1 in appendix for numbers excluded). Further details for each study are available in Appendix A.

Study	Country (Region)	Year of Recording	Number of Subjects Included	Device Used	Age Range (Years)
ALSPAC	United Kingdom (Bristol)	2003 - 2007	6935	Actigraph GT1M	10 - 15
CLAN	Australia (Melbourne)	2001, 2004, 2006	1202	Actigraph GT1M	5 - 18
EYHS	Denmark (Odense)	1997 – 1998, 2003 - 2004	1814	Actigraph GT1M & GT3X	8 – 18
EYHS	Estonia (Tartu)	1998 - 1999	662	Actigraph AM 7164	8 – 17
EYHS	Norway (Oslo)	1999 - 2000	398	Actigraph AM 7164	9 - 10
EYHS	Portugal (Madeira)	1999 - 2000	1256	Actigraph GT1M	8 – 18
HEAPS	Australia (Melbourne)	2002 – 2003, 2006	1453	Actigraph GT1M	4 – 16
KISS	Switzerland (Aargau and Basel)	2005 - 2006	532	Actigraph GT1M	6 - 14
NHANES	USA (National)	2003 – 2004, 2005 - 2006	5284	Actigraph AM-7164	6 – 18
Pelotas	Brazil (Pelotas)	2006 - 2007	457	Actigraph GT1M	13 - 14

Excluding the 2003 NHANES sample, most of the studies included here recruited individuals from regions within each country rather than broadly across the nation. As such, these studies may not be truly representative of the countries from which they draw. This has previously noted for the ALSPAC study, participants in which are more affluent than the national population.[213] Sample sizes also vary across the studies which may alter their representativeness, with samples ranging from under 400 amongst Norwegian children in EYHS, to over 6000 British children contained with ALSPAC before data reduction (See Figure S A-1 in appendix for numbers excluded), which may further impact confidence intervals in analyses.

2.1.3 National Health and Nutrition Examination Survey (NHANES)

The National Health and Nutrition Examination Survey is a repeated cross-sectional study undertaken across the USA and aims to be broadly representative of the national population, with some oversampling of minority groups to ensure statistical power.[260] For the purposes of comparing trajectories of activity with age to the BaYaka, data from the 2013 survey is used. In 2013, wrist-worn accelerometer data was collected from all individuals aged 3 or older. Individuals wore the device continuously for a week, providing an output for both the whole week, for each day, and each hour within each day. As in ICAD, the exact start date of the recording is not available due to privacy concern. Instead, the start date for each file was set to be between the 1st and 7th of January on the year of recording, with the date picked to match the day of the week on which recording started.

2.1.4 Millennium Cohort Study (MCS)

Commissioned to capture the lives of children born in the new century, the Millennium Cohort Study (MCS) recruited almost 19,000 children born between 2000 and 2002.[261] With survey waves every few years, data on almost all aspects of their lives has been captured, including markers of their biological, neurological and behavioural development alongside information about their families, neighbourhoods and social groups.[261] Eight survey waves have already been conducted, documenting these now young adults lives at age 1,3,5,7,11,14,17 and 22 years. Participants were recruited to be broadly representative of their wider UK birth cohort, drawing from varied socio-cultural backgrounds in the four UK home nations.[261] Throughout the study physical activity has been captured in most waves using survey based measures. In two of the waves an objective measure of physical activity has supplemented this. In the age 7 sweep, waist-worn accelerometer data is available from a subset of 8939 children, who wore the devices for 7 days, removing the device when sleeping or when in water.[262] At age 14, a subset of 4,533 children were asked to wear a wrist worn device for two randomly allocated days (one weekday, one weekend).[263] From the age 14 sweep, data on the mean acceleration as well as the time spent in MVPA or sedentary thresholds his given.

2.2 *Quantifying physical activity.*

Numerous methods have been developed to discern the levels of activity that individuals engage in. Though there are various subjective and objective means of infering activity levels, at their core they all aim to assign a numerical value to the amount of self-propelled movement an individual undertakes, which can then be used to compare between individuals and against target values. While the analysis in this thesis focuses on the output of accelerometers, multiple forms of activity quantification are assessed throughout the thesis. Each has its own strengths and weaknesses, with the choice of technique reflecting the best trade-off given the study design.

2.2.1 *Subjective measures of activity.*

Subjective and observational methods of quantifying activity are a common form of data collection that centre on either a retrospective or prospective account of daily activity levels. Compared to objective measures of activity, these are relatively low cost, allowing for larger sample sizes. Additionally, with standardised forms that can be translated into other languages, large multinational samples can be collated. While there are limitations that objective measures aim to address, subjective measures remain a core part of physical activity research.

Self-reported activity is amongst the most common way of discerning activity patterns. Survey based methods exert a relatively low burden on the participant and are typically inexpensive. Physical Activity Questionnaire (PAQ) based measures can therefore be useful in establishing an approximate amount of activity in a large group of individuals for a relatively low cost. They involve asking the participant, or someone familiar with their daily behaviours (such as a parent or guardian), to estimate the volume of time spent in different activities. They can broadly group multiple behaviours into one category (i.e. “activities like carrying light loads, bicycling at a regular pace, or doubles tennis”) as seen in the International PAQ (IPAQ) survey or subdivide to time spent in particular activities, with separate entries for “cycling” and “tennis” (as in the Recent PAQ survey). They can ask the participant to report the activities over different time scales, whether that’s what they would do on a typical day (i.e. “On average, how much time each day do you spend walking?”), they can focus on a particular day (i.e. “Last Tuesday, how much time did you spend sat watching TV or on a computer?”), over the past week (as in the IPAQ and GPAQ) or month (as in the RPAQ), or in the case of the EPAQ over the last year.

An issue with self-reported measures of activity is that they can be biased toward more memorable activities, especially with survey focussed on a longer time window (like EPAQ).[264] Individuals are typically better at recalling how much time they spend in sport or leisure activities, but are less reliable reporters for lower-intensity and life-style activities such as walking, house work or socialising. The same issues are present when measuring time spent sedentary, with questionnaires instead focussing on more readily remembered behaviours.

Diaries and logs can also be used to instead to address some of these recall biases. These methods involve the participant noting down their current behaviour or activity at a given interval. Though it still misses some transient behaviours, the advantage of using a diary or log rather than a survey is that it captures the dominant activity type at a regular interval. The downside of these techniques is that they are comparatively time consuming for the particpant. While use of mobile applications can aid this, with regular notifications delivered to the participant, there is still the risk that participants retrospectively complete their log at the end of the day, increasing the risk of recall bias, or runs of missing data. Additionally, being undertaken prospectively rather than retrospectively may influence the behaviour of the participant so that they appear more active than they may otherwise be.

An alternative that is common in anthropological studies is of focal follows. Focal follows (and similar techniques) follow a similar methodology to the logs, but use an external, third party (often a researcher) to note down the behaviour engaged in by the participant. As before, these can either note the behaviour engaged in at a regular interval or note the time at which individuals enter and exit particular behaviours. The limitation introduced here is the number of individuals that a researcher can follow at one time. While multiple individuals can be ‘followed’ simultaneously, they must all be in sight of the researcher, which restricts the number of participants that can be included on a given day.

Once behaviours are reported or recorded, these then need to be translated into an approximation of physical activity. This can be a time estimate; in the case of IPAQ individuals report how much time they spend each week in “activities that take moderate physical effort and make you breathe somewhat harder". Alternatively, where individual behaviours are reported, Metabolic Equivalents (METs) can be used to quantify the energy expended.[265] The value (in METs) represents the rate of work compared to the resting metabolic rate. Typically, this involves recording what behaviours individuals are doing, when they are doing them and for how long. The relative energetic burden of these behaviours can then be estimated based on pre-existing figures for a given behaviour, with the value (in METs) representing the rate of work compared to the resting metabolic rate, often interpreted as 1 kcal/kg/hour. These values are often established in a lab setting, in which gas calorimetry is used to accurately infer the rate of energy expenditure.[265] These reference expenditures are usually quantified at an array of intensities; running is broken down into varying speeds: "Running (4mph)", "Running (5mph)" and "Running (5.2mph)" and other activities broken down into sub categories like: "Polishing: Floors" and "Polishing: Furniture".

The advantage of such a method is that, with others contributing their observed metabolic rates, it does not require any expensive lab equipment or recording devices for the individual study. While it can be time consuming if a researcher directly translates a behaviour into a metabolic equivalent, self-report time-use diaries are increasingly digital, allowing predefined behaviours (and therefore METs) to be selected from a list. However, many behaviours are transient (I.e. a "20 minute walk to the shops" may actually involve: walking, but at a mixed pace, stopping in the store, carrying items, pushing a trolley), meaning that the lower the resolution of the recording (continuous scans vs. 5 minute scans vs hourly scans) the lower the accuracy of the estimate. Secondly, it requires behaviours to have been accurately recreated and quantified in a laboratory setting, which are often located in clinical or academic settings. This introduces issues regarding the choice of subjects used to quantify, what behaviours are carried out, and how they are carried out. For subsistence populations, many of the behaviours do not have a validated MET estimate, as such, the closest proxy behaviour in post-industrial populations is used to estimate energy expenditure.

While self-reported and objective measures can have low degrees of agreements, comparisons between different self-report and direct observation methods (i.e. focal follows) can have a high degree of agreement (75-85%).[266] Additionally, as highlighted in a review of activity measures in pre-school children, while the evidence quality of proxy-measures of activity (adult reported account of children's behaviour) is weak, it can provide use contextual data.[267] For instance, while an accelerometer may give a better account of total activity, survey measures may provide additional context on the situation and setting in which the activity was carried out. As such, if the interest was in assessing how much activity is undertaken as a leisure activity, survey measures can be more useful in discerning the situation of the activity than an accelerometer alone.

2.2.2 Objective measures of activity.

Objective measures of activity act to either quantify the amount of movement undertaken, or the amount of energy used to undertake that movement. To do so, they use techniques that do not require a self-reported or inferred volume of activity, instead generating a continuous, numerical outcome of activity. A review of 63 reviews supports the view that objective measures of physical activity offer a more accurate method of inferring physical activity than surveys, recall and observation[268] with a separate review finding self-reports to be liable for both over and under reporting.[269] . An early review (Kohl et al., 2000) of objective and subjective measures of activity observed low to moderate agreement between self-reported and objective measures.[270] While the correlation between a recall survey and wrist-based accelerometery was low to moderate in a study of US children.[271] A separate study of parents and children observed that in addition to a low level of agreement, self-report measures were prone to over and underreporting activity compared to accelerometers.[272] With the same study observing that self-reported measures had less internal validity within individuals between study blocks than accelerometers.[272]

Though more reliable, an amount of disparity remains between different objective measures.[268] There are two broad groups of outcomes to objective physical activity measurement, though each can be used to estimate the other. The first set of techniques aim to represent the amount of movement undertaken, while the second looks to quantify the amount of energy used by activity. Various techniques are employed to objectively capture activity but accelerometery is increasingly becoming the dominant technique by which patterns of physical activity are objectively recorded. All analyses in this thesis use accelerometer derived measures of activity.

2.2.2.1 Accelerometry

Accelerometers measure activity by quantifying the amount of acceleration the device experiences. Devices often come in one of two forms, uniaxial or triaxial. Uniaxial devices measure the acceleration experienced in one plane of movement, most commonly in the vertical plane, and these are often found in early waist worn devices. Triaxial devices contain sensors to measure activity in all planes of movement (Vertical, Horizontal and Lateral) and are worn in multiple body positions. Development of the technology includes better batteries, allowing for full weeks of recording at higher rates of recording, with modern devices commonly collecting data at 1/100th of a second. More compact sensors have also allowed for reduced device size, with waterproofing allowing the device to be worn throughout most daily activities.

There are general limitations to most accelerometers. First, devices report the amount of acceleration, not the amount of force required to produce that acceleration. Accelerometers therefore undervalue the amount of activity involved in load bearing exercise. For children, the accelerometer profile of walking is the same regardless of whether the child is carrying a heavy rucksack or not. Some other activities are undervalued by accelerometers, with cycling being notably underrepresented.[273] A central issue to accelerometer studies is the restricted ability to compare between studies compared to self-report studies.[266] This is particularly the case where studies are either using different devices, different wear protocols, differing means of processing the output, or different cut points to separate between thresholds of activity.[274] The effect of different cut points was particularly apparent in a review of 35 studies using different cut points in which the proportion of children meeting WHO guidelines of 60min of MVPA per day varied between 3% and 100%.[275] There can also be variation in the output from devices; a study of 321 women using the same device (Actigraph GT3X+) in two body locations (waist vs. wrist) found a 41% difference in the estimated amount of physical activity.[276]

Early iterations of accelerometers were worn on the waist, with some devices continuing to be worn as such. The device is typically attached to an adjustable belt that is worn on the hips. Early devices (including the GT1M used in ALPSAC and the Pelotas Study included in the ICAD dataset)[259] were relatively large, sitting more than a couple centimetres off the body, and were uniaxial, measuring movement in one plane. A hip placement suited these devices, as the size presented less of an inconvenience to the wearer during everyday activities, and with the torso largely remaining vertically aligned throughout waking activities, suited a device that could only measure movement in one plane. A lack of waterproofing in early devices meant they had to be removed when showering or swimming, and their size meant that individuals were encouraged to remove them during sleep due to the potential discomfort. Newer devices are typically triaxial, waterproof and smaller in size. In the chapters analysing activity patterns in the ICAD, a mixture of uniaxial and triaxial waist worn accelerometers were used.

The reduction in size of sensors and batteries allowed triaxial devices to be developed into a wristwatch-like form, which presents less interference with everyday activities. With the device typically placed on the non-dominant wrist, movements carried out in place, such as cooking, can be captured in addition to whole body movements. Devices can be worn continuously due to both the reduced size and improvements in waterproofing, allowing for the full 24hr period to be accounted for, while also reducing the risk of non-wear periods as the participant has less cause to remove the device. While wrist placements provide a better account of light intensity, 'everyday' activities, the representation of sedentary activity is limited. Namely, there is growing interest in examining sedentary behaviour as a reciprocal, but separate determinate of health, with a focus on posture, that wrist-worn accelerometers provide little meaningful output for.[277] With different placements leading to differing outputs, it is difficult to directly compare outputs between wrist and waist worn devices.[276] Accordingly, waist-worn studies continue, including in the ALPSAC study that continues using a waist placement to ensure continuity between accelerometry sweeps.[259]

Accelerometers have also been developed for other body placements. Devices have been attached to the thigh using adhesive patches. These tri-axial devices are particularly effective at differentiation between sedentary behaviours, being able to discriminate between a horizontal position, which would represent time spent sitting or laying, or a vertical position which would infer a standing position.[277] Neither waist nor wrist worn devices can make such estimations. However, thigh worn devices encounter similar limitations to waist-worn devices in quantifying stationary activities. The use of adhesive patches on skin can cause discomfort for participants, and more frequently so in warm and humid climates, making them less suitable for use in the studies involving the BaYaka. Equally, the device can be uncomfortable to wear for anyone also wearing a bra or similar item of clothing.

Chest mounted accelerometers have also been employed. The output of the recording is comparable to that of waist-worn devices, giving good resolution to ambulatory activity but limited in stationary activities. The benefit of these devices is that they are often combined with a heart rate sensor (also referred to as combined sensing), giving both a measure of movement and the relative effort required. As before these devices encounter similar issues of adhesive patches, combined with being placed in a relatively invasive position.

2.2.2.2 Alternative means of quantifying physical activity.

Early pedometers were akin to early uniaxial accelerometers, and they offer an easy, and affordable means of quantifying activity. They are limited in what behaviours they measure (ambulatory exercise) but can be readily employed. The devices provide a simple count measure of the number of steps undertaken, which can then be compared between individuals. The availability of step count data has increased with modern smartphones. Phones and smart watches will often capture the data that can then be self-reported, or via apps can be report automatically. Key limitations to pedometry include the narrow breadth of behaviours captured and the lack of nuance within the data (i.e. walking or running the same number of steps appears the same). Additionally, recordings are only as reliable as the position in which the device is carried. If a phone is used, it can provide an estimate akin to a waist-worn pedometer, but will underestimate steps if carried in a bag, or if the device is not carried on the person at all times.

Global Positioning System (GPS) devices have also been employed to estimate activity. These devices estimate an individual's location via triangulated from satellite signals. At lower frequencies, the approximate area used by an individual can be calculated (hourly or daily), with higher frequencies (minute or second) allowing paths, and therefore distance travelled to be calculated. Lower frequencies allow for a longer recording period (multiple days to weeks), but improvements to battery technology mean wearable GPS devices can record at least a day's movement at a high frequency. For individuals whose sole mode of transport is walking, the time and distance covered can be used to estimate the ambulatory activity. Complementing this is that modern devices can combine both a GPS and other sensors, with consumer grade devices now often including both an optical heart rate sensor and an accelerometer. However, the raw data from these sensors is often 'black boxed', with pre-processed outputs, which restricts the ability to compare the outputs with those from any other device.

Compared to the other methods described, GPS is the only one to give an accurate account of location. However, the ability to infer movement from this is limited. As previously outlined, the resolution will vary by the frequency of recording, but this is traded off against recording length, due to both battery and memory constraints. In open areas with a clear view of the sky, consumer grade GPS units are accurate to within 10m. However, in built up areas, or those in canopy cover (such as the BaYaka), the reflection of the signal from building or trees can cause the location to 'bounce' as the approximate distance from the satellites moves (Figure 2-2).

Figure 2-2: Output from a Garmin Forerunner 935 GPS device compared to a known route through London's Canary Wharf, an area with numerous skyscraper buildings. Colour toned line represents GPS estimated location. Red dashed line represents true route followed.

2.2.3 Estimating energy expenditure

While the above methods look to capture the amount of activity undertaken, some methods instead quantify the amount of energy spent on movement. Of these, gas calorimetry is one of the most accurate but involved means of estimating energy expenditure is. This technique involves a quantification the rate of exchange between the oxygen consumed by, and the carbon dioxide produced by metabolism. Typically, this is achieved in one of two ways, either by using an enclosed space, typically a large, sealed room, or a breathing mask. Both methods are suitable for calculating accurate calorie estimates, such as creating the MET equivalents mentioned earlier, but are limited in their ability to capture 'free living' activity patterns. While a mask can be used in the field, the requirement of capturing all expired air places restrictions on an individual eating or drinking during the protocol, and the individual is somewhat encumbered by either the air supply or the processing equipment.

Doubly labelled water is an alternative technique that indirectly measures the volume of carbon dioxide produced, but unlike gas calorimetry can be used in free living subjects. The technique has participants drink a dose of atomically labelled water, produced with isotopes of both hydrogen and Oxygen (^{2}H and ^{18}O), which mixes with the pool of water already in the body. The marked oxygen from the marked water is used in respiration, while the ^{2}H component leaves the body as a metabolite. The ratio of which in a urinary sample can then be used to calculate the rate of CO_2 production, and thus energy expenditure. While this is the 'gold standard' of estimating energy expenditure in free living populations, there are constraints to its use. The largest of which is costs due to the requirements of enriching, storing and analysing isotopically enriched samples (at the time of writing, a startup-company called Calorify have started offering a one-off test for $1000). Together, this restricts its use to smaller scale studies. Further complicating the use is that samples need to be kept chilled, which limits its use in field sites away from electricity grids and refrigeration. In Pontzer et al's (2015) doubly labelled water study with the Hadza,[87] samples were chilled with a supply of dry ice (Nitrous Oxide) and flown back to the USA for mass spectrometry.[278] Finally, a body of calibration work is needed beforehand to calibrate the ratio of isotopes in the body, calibrate each participants rate of excretion and to establish the BMR to infer the inflections caused by physical activity.

A more affordable approach that aims to estimate energy expenditure is the use of heart rate monitors (HRM). With heart rate reflecting the rate of oxygen delivery to muscles and organs, inflections in heart rate above the resting rate can be used to estimate the overall energy expenditure due to non-basal processes. These devices measure heart rates either via the electrical discharge of the heart beats, or via the pulse of blood flowing through blood vessels. The first, also referred to as an electrocardiogram (ECG), involves the placement of a device on the chest, as close to the heart as possible, where an electrode is placed on the skin either side of the heart, which records the electrical current produced when the heart contracts. This method is often more accurate than optical measurements but can be limited by the requirement to wear the device against the skin and close to the heart.

Optical devices can tackle these limitations as they can be placed anywhere on the body, provided there is a suitable amount of blood flow near the skin but are often placed on the wrist or arm. Optical pulse measurements of heart rate measure the varying flow of blood through blood vessels as the heart beats.[279] These devices are often less accurate than electrical techniques but are more convenient to use.[280] Additionally, numerous consumer grade devices have optical heart rate monitors built into them, creating a potential pool of participants without the need of too much expenditure.[279] However, these devices are often owned by individuals who already have some interest in measuring their energy expenditure so may not produce representative samples. As with all the following methods of estimating energy expenditure, the calculation of the amount of energy used by physical activity is calculated from the total energy expenditure and the basal metabolic rate (i.e. the amount of energy used while a person does nothing), with an adjustment for the thermal effect of feeding. Assuming the calibration of the basal metabolic rate is accurate, this should provide a good estimate of the energy consumed by movement, but there are reasons other the movement that can raise metabolic rates above resting (inc. immune and stress responses).

2.2.4 Selecting an appropriate means of quantifying activity.

There is no single 'best-practice' approach for studying physical activity profiles, instead, the right measure is the one that suits the constraints of the study. Amongst studies with larger samples or more distributed individuals, survey-based measures can offer an affordable means of collecting information on individuals' active behaviours. These subjective measures can equally be less demanding on the participant than a prolonged wear protocol using an objective measure. While self-reported and objective measures can have low degrees of agreements, comparisons between different self-report and direct observation methods (i.e. focal follows) can have a high degree of agreement (75-85%).[266] Additionally, as highlighted in a review of activity measures in pre-school children, while the evidence quality of proxy-measures of activity (adult reported account of children's behaviour) is weak, it can provide use contextual data.[267] For instance, while an accelerometer may give a better account of total activity, survey measures may provide additional context on the situation and setting in which the activity was carried out. For instance, if the interest was in assessing how much activity is undertaken as a leisure activity, survey measures may more useful in discerning the situation of the activity than an accelerometer alone.

However, where the interest is in quantifying overall activity (regardless of context) there is emerging evidence that self-report and subjective measures are less reliable than objective measures. An early review (Kohl et al., 2000) of objective and subjective measures of activity observed low to moderate agreement between self-reported and objective measures.[270] Correlation between a recall survey and wrist-based accelerometery was low to moderate in a study of US children, though a marginally stronger correlation for sedentary behaviours.[271] A separate study of parents and children observed that self-report measures were prone to over and underreporting activity compared to accelerometers. Additionally, self-reported measures varied more between study blocks than accelerometers did.[272]

Though arguably the most common approach to objectively measuring activity, accelerometers are not a perfect measure. A central issue is the ability to compare between studies, particularly where studies are either using different devices, different wear protocols, differing means of processing the output, or different cut points to separate between thresholds of activity.[274] The effect of different cut points was particularly apparent in a review of 35 studies using different cut points in which the proportion of children meeting WHO guidelines of 60min of MVPA per day varied between 3% and 100%.[275]

Accelerometers record the amount of movement detected by the device, which is processed in a way to attempt to capture the latent concept of human movement. When this output is translated to an estimate of active energy expenditure predicted values often underestimate the amount of energy spent on movement.[268] This may occur for a few reasons, but this is primarily because accelerometers do not record energy expenditure. As such, any attempt at converting accelerometer counts to energy is dependent on the accuracy of the conversion factor.

For the research conducted in this thesis; for the ICAD, the use of waist-accelerometers was predetermined. When choosing a means of quantifying activity in the BaYaka the aim was to use a method that objectively quantifies patterns of movement in a free-living population. The device needed to be able to quantify a broad selection of active behaviours, both ambulatory and static. It also needed to be able to record for multiple days without interfering with the behaviour of the participant. The primary aim was to quantify activity amongst the BaYaka, but a secondary aim was to compare this data to other populations, so the device must provide an output that is comparable to other studies. Accordingly, wrist-worn accelerometery was selected as the most appropriate means of recording activity.

2.3 Analysing activity patterns.

Across the datasets included in this thesis various means of processing the accelerometery data are employed. While all of the various methods of processing accelerometer outputs aim to summarise the same latent concept (the acceleration experienced by the device) they do so in differing manners. In this thesis the activity outputs include counts (as used in ICAD), low pass filters (as used in the BaYaka and MCS) and high pass filters (as used in the 2013 NHANES). For the ICAD, MCS and NHANES datasets, activity data was processed by the data holders with only the output made available for analysis. For the BaYaka, data processing was conducted as part of this thesis.

Across all of these studies, the output includes an overall summary of all movement, which is then be subset into the amount of time spent in differing thresholds of activity. The exact cut-offs vary between devices and processing techniques, but the standard thresholds employed are sedentary, light, moderate, and vigorous activity (Table 2-2), with the final two often grouped to form MVPA (Moderate to Vigorous Physical Activity). While raw measures are preferable for an estimate of overall activity, volumes in thresholds allow for activity to be broken into different bands of activity, allowing for the distribution of active behaviours across different intensities to be examined. Additionally, measure like MVPA better translate onto existing self-report measures and guidelines. While there is little consensus on absolute cut points between these thresholds, a threshold approach broadly tries to separate activity into categories like those in Table 2-2. An additional incentive to retaining thresholds is that members of the public can more readily comprehend 'χ minutes of time in activities with an intensity similar to running' than 'χ counts per minute'.

Table 2-2: Activity thresholds and example behaviours based on Metabolic Equivalents[265,281]

Intensity	Example Behaviours
Sedentary	Sitting, watching tv, office work, knitting,
Light	Cleaning, sweeping, gardening, walking
Moderate	Moving furniture, chopping wood, walking briskly (>3.5mph) or climbing stairs, Bicycling at light effort
Vigorous	Running, carrying heavy items up stairs, using heavy manual tools

However, the choice of threshold cut points when processing the output can alter findings. A study investigating the cut points used found that dependent on the boundary used the rate of adherence to guideline levels of physical activity (150 min/week) varied from 6.3% to 98.3%.[282] In the present thesis, Evenson cut-points are used when analysing count based data in the ICAD dataset,[283] and using thresholds recommended in GGIR[284] and as employed in the Pelotas,[285] MCS[263] studies when analysing milli gravitational outputs from the BaYaka and Millennium Cohort Study datasets.

2.3.1.1 Activity counts: The ICAD.

Early accelerometers measured activity using a unit called counts, and these continue to be used by some brands to ensure backward comparability. These accelerometers work by detecting the amount of movement experienced by a sensor when deflected by the acceleration of the device. Initially, these would work by counting the number of times the element within the sensor was deflected enough to complete an electric circuit, with greater forces completing the circuit more often, resulting in higher counts. The number of counts over a period of time can then be used to calculate the relative intensity of movement, with greater movement intensity causing greater counts. To standardise the time period, these are often presented as the average number of counts per minute (cpm) but have also been presented as counts per day. This can also be converted into a threshold measure of number of minutes with a count above a threshold.

Modern devices work in a slightly different manner, by calculating the resistance within the electrical circuit, and applying a threshold to calculate the number of counts that would equate to. These can also then take into account the three dimensions of measurement used in modern devices and either incorporate these to give a triaxial summary or discard two axis and present the counts from the vertical axis alone. This reduction of dimensions is employed in the ICAD dataset to preserve the comparability between studies using older and newer devices (Table 2-1).[259]

2.3.1.2 Low Pass Filters: BaYaka and MCS datasets.

Low pass filters are designed to separate out signals that could be of human origin and exclude frequencies in excess of what a human could produce through their own, self-powered movement. For physical activity research, this is typically set at around 15hz to capture activity near the human maximum (for a drummer this would represent 900 beats per minute from one hand), but aims to exclude frequencies above the human maximum, such as being in a car. Euclidean Norm Minus One (ENMO) as used in the BaYaka and MCS employs a low pass filter. Here, following the 15hz filter, a fixed value of 1g is subtracted, as this is the signal from earth's gravity which would occur if the device was perfectly motionless. Movement is presented in milligravitational units (mg) minus the Euclidean norm of one gravitational unit (ENMO).

2.3.1.3 High Pass Filters: 2013 NHANES

High Pass Filters take the same initial approach to remove frequencies outside of the human range. Subsequently, they then apply a high pass filter to remove all low frequencies that are unlikely to be of human origin. This differs from an ENMO approach as it does not treat gravity as a constant, instead treating as a low frequency signal to be filtered out. In the present study, the monitor-independent motion sensing (MIMS) units reported for the NHANES 2013 data are calculated in this manner.

2.3.2 Processing BaYaka activity data with GGIR

Where accelerometry data is processed directly as part of this thesis, it is done using GGIR in R.[284,286] Initially, the acronym stood for "GENEActiv and GEANEA data in R" but this has been abandoned in favour of just using the acronym with the package expanding to include multiple device outputs. In the mode in which it is employed in this thesis, GGIR employs a low pass filter as described above.[287] This output can then be presented across varying recording lengths and subset into thresholds to represent the proportion of time within a time period spent in sedentary, light, moderate or vigorous activity.

For both field visits to the Republic of Congo (Chapters 5 & 6), GENEActiv accelerometers devices were used to quantify movement (GENEActiv Original; Activinsights Ltd, Kimbolton, Cambs, UK, http://www.gene-activ.org/). Prior to distribution, devices were configured to operate at the greatest possible frequency (100hz), and to report the mean acceleration for each 5 second period. After being collected back, accelerometer recordings were processed using GGIR.[288] Reflecting the study protocol, the maximum recording length was set to 7 days from the start of recording, with the first and final hour or recording excluded to account for any change of behaviour when the particpant was being set up with the device and when the device was being collected back. Data was calculated in 24-hour windows from midnight to midnight, based on West Africa Time (UTC +1 hour).

Accelerations, calculated in milligravitational units (mg), are returned as both a continuous measure across the recording, and also subset into the amount of time in standard thresholds of activity (Sedentary ≤ 50mg < Light ≤ 100mg < Moderate ≤ 400mg < Vigorous).[285,289] MVPA is presented as the sum of all the minutes in moderate or vigorous intensities. Times in each threshold are unbouted, meaning all epochs in a given threshold are included. This contrasts to bouted measures, as employed in Raichlen et al., (2017),[130] in which a certain proportion of a time window must be within a given threshold to be counted, for MVPA this has typically been set as 80% of a 10 minute window.

Sleep was calculated from periods of time in which the device was in a sustained, inactive state.[290] This was classified as any block of 10 minutes, in which the average movement of the device is less than 5° in any axis over each 5 second epoch. The algorithm defines the longest sustained inactive bout within each day as sleep, allowing for the sleep bout to be broken for up to one hour before separating it into two bouts of sustained inactivity. From this the estimated onset and end of sleep windows was calculated from the final and first timepoint in each day in which an individual was not in a device defined bout of sleep. An example output from a BaYaka child is available in Figure S D-3, demonstrating differences between sleep and wakeful activity as detected by the device.

In Chapter 5, data was collapsed to one entry per person by averaging the mean volumes of activity across the available recording to present an account of a 'average' day. This decision was made due to the variable recording length in the collected data. In 2018 individuals some individuals had over 24hs of recording but only one night of recording. With GGIR defining a day as either one complete midnight to midnight phase, or one wake to wake phase, these individuals would have been excluded if only complete days were used. As such, average days were employed as GGIR fills in incomplete sections of the day from complete sections of other days to create one entry per person. For Chapter 6 the study protocol was to have multiple complete days of recording to allow multiple days per person. Here data is output as each day of recording, and as each hour of each day.

2.4 Analysing data.

Unless otherwise stated, all analyses were carried out in R using R Studio.[286] In analysing the activity outputs, two main forms of modelling are employed. Linear models are used in chapters studying the BaYaka, using fixed or mixed effects where appropriate. Generalised Additive Models of Location Shape and Scale (GAMLSS) are employed in chapters examining the ICAD, which in addition to examining differences in the mean, allows for statistical comparison of the median, standard deviation, and skew.[237] GAMLSS is underpowered in small sample sizes, so could not be employed in the BaYaka datasets. Additional details on the underlying mechanics of GAMLSS is detailed in section 3.2.4. Sensitivity analyses were conducted where appropriate. Detail of which is in the relevant analysis chapters, with model outputs from sensitivity analyses available in the supplementary material.

Prior to any analysis, all data was checked for any notable outliers or implausible values. GGIR marks and flags any implausible accelerations, including periods with no movement that typifying non-wear periods. Neither of which were detected in the BaYaka sample during the study period, with non-wear only detected on an individual's final day of recording, representing the time between removing the device and stopping the recording. In this study, the recording ended when the device was connected to a computer. For the ICAD, all activity data was checked by the data holders prior to inclusion, as such when examined prior to analysis no implausible values were observed.

Chapter 3 Gender differences in the distribution of physical activity in the International Children's Accelerometry Database

Main Objective: Examining differences in the distribution of childhood physical activity between genders in a multi-national sample using descriptive and statistical methods.

Background: Physical activity in childhood influences health and development in both the short and long term. Previous studies have frequently observed gender to be associated with volumes of physical activity, yet the focus has largely been on summary measures and statistics rather than the full spectrum of activity. Here differences in the full distribution of physical activity between genders is examined in a multi-national sample of children.

Methods: Generalised Additive Models of Shape Scale and Location (GAMLSS) are used to investigate gender differences in 1) average physical activity levels (mean and median); and 2) between-person variability (SD). To do so, the harmonised International Children Accelerometry Database (ICAD) is used, including 15,461 individuals (Boys: 48.3%) from 9 countries. Analyses were conducted for multiple outcomes: across each activity intensity (Sedentary, Light, and Moderate-to-Vigorous (MVPA)) and a summary measure (counts per minute (cpm)).

Results: Sizable gender differences in the distribution of activity were found for moderate to vigorous activity and counts per minute, with boys having higher average levels (+38% in MVPA, Boys: 62.51min/day, Girls: 42.94min/day; +20% in cpm, Boys: 650cpm, Girls: 533cpm), yet substantially more between-person variability (+30% for MVPA, Boys:- 31.84, Girls:23.73 ; +17% for cpm, Boys: 236.11, Girls: 200.34), but with values less positively skewed than girls. Conversely, there was little to no difference between genders in the distribution of sedentary or light activity.

Conclusions: Inequality in overall activity (cpm) between the genders was driven by moderate-to-vigorous activities. The greater variation observed for boys implies that this difference was not caused by the whole distribution of boys undertaking more, but due to a more sizeable subset undertaking leisure time MVPA on top of any compulsory activity. This suggests a need to consider the underlying distribution of activity in future research; for example, interventions which target gender inequality in MVPA may inadvertently lead to increased inequality within girls.

3.1 Introduction

Introduced in section 1.1.2, physical activity's relationship with health and wellbeing is well documented and is present across the lifecourse.[76] Though temporally removed from the mortality risks associated with a lack of physical activity, activity levels during childhood and adolescent have implications for health and development both in the short and long term. Yet children remain chronically inactive, with over 80% of children globally estimated to be inactive.[94] As such, a focus is often placed on tackling inactivity in children in a way that also reduces the disparity in activity between groups.[291,292]

3.1.1 Boys and girls activity within the International Children's Accelerometery Database

Discussed in section 1.1.3.3, gender is frequently observed to be a correlate of objectively measured physical activity in youth samples, with boys near consistently recording more activity than girls across childhood and adolescence.[111,112] Within the ICAD literature reviewed (See Table S A-1) all of the 7 studies using the ICAD dataset to explore the association between gender and physical activity observed boys to have a higher average volume of MVPA and lower average volumes of sedentary behaviour, as measured with waist worn accelerometers.[7,8,293–297] Boys were more active at all ages,[294] but the scale of difference did vary between studies.[8] Limited volumes of research have been done outside of post-industrial populations, but a similar effect of gender on physical activity was seen in a review of activity patterns in sub-Saharan school aged children using either subjective or objective measures of activity.[110] Further, in a multinational self-report study of over 60,000 African adolescents, boys similarly engaged in more activity, but this centred on sports and leisure activities.[298]

Within the available ICAD research, few pieces have explored variation within light activity, with none to date observing any statistically significant difference between the genders. Of the research undertaken to date, both boys and girls undertook between 5 and 6 hours of light activity per day. In a paper by Sherar et al., (2016) girls were observed to undertake 30 minutes less light activity per day compared to boys.[299] Though this observation was not statistically analysed, the standard deviations for each sample mean was at least twice the difference between the sample means. In a study by Aadland et al., (2020) the difference between boys and girls within age groups of either 6 to 12 years, or 12 to 18 years, was less than 11 minutes per day for light activity between 100cpm and 2000cpm (approximate to the cut-offs employed by Evenson et al.,(2008)).[105,300]

3.1.2 Gender as a potential driver of variability

Lacking amongst existing research is a developed understanding of how patterns of activity are not only patterned between groups, but how this interacts with distributions within groups. Of the available ICAD literature, no studies examined the full distribution of individuals across all activity intensities. In a separate large cross-sectional study of self-reported physical activity in adolescence across 52 countries, a gender disparity was observed with boys undertaking more activity.[116] Some evidence from this study indicated that some of the difference in the genders could be driven by boys having a greater volume of individuals at the highest activity levels. However, no formal analysis of differences in distribution was employed in this study, and drawing from self-reported activity may lead to misreporting of activity, with those who partake in formal or structured activity overreporting their activity, while informal activities may be underreported (See section 2.1 for a discussion of activity measures).[264]

Understanding the distribution of individuals may help highlight the underlying drivers of differing activity levels between groups. In the context of the present research, more boys being observed to undertake 60min/day of MVPA could reflect either a shift of the entire distribution upward or it could result from a larger subset of boys undertaking notably more activity, increasing either the spread or the skewness of the data. For the former scenario, tackling gendered inequality in physical activity should focus on why girls are less active are boys. For the second scenario, the focus should be instead on understanding why the subset of very active boys is larger than the subset of girls.

Differences in distributions between the genders may depend on the choice of activity metric or threshold. If the previously observed differences between the genders in volume of activity is driven by the most vigorous activities, namely those falling within moderate-to-vigorous thresholds. For light activity, those shaped by habitual activities of daily life, like school commutes or in class behaviour it may be that there is less difference between individuals. Where individuals have less control of how much activity they do, less variation is likely to be observed. Between the genders, it may be that less variation between individuals is seen.

Expanding on the potential variability within thresholds, it may be that within MVPA, there is a greater variation around the mean and a greater potential for the data to be positively skewed. While it is unlikely that any child is completely inactive, it is possible that none of their activity comes from the highest intensities. For an accelerometer, MVPA is consistent of intensive activities such as sport or active play. [301–305] As such where there is greater variance in access to sport the greater the likely difference in the volume of MVPA.

However, for an individual to spend more time in MVPA, this must therefore come at the cost of time in light intensity activity, sedentary behaviour or sleep. As such, gender differences in distributions may reciprocate across different thresholds. Across populations individuals should receive roughly equitable access to play within school settings. If one of the drivers in differences in MVPA is the volume of active play in boys, it may be that girls have a reciprocal uplift in light or sedentary activity.

3.1.3 GAMLSS as a method to statistically examine variability.

While there are methods to examine differences in variability of data in addition to the mean,[238] GAMLSS (Generalised Additive Models of Location, Scale and Shape) is an underutilised approach to do so.[237] Though it is more often used as a method of generating quantile curves for physical activity[306] or anthropometric measures,[147,307] it is capable of exploring how the distribution of populations vary from one another according to the mean, variability, and skewness; and the possible risk factors for each parameter of the distribution while accounting for covariates. To date, such an approach has been underutilised within the epidemiology literature, with a broad scope search through Web of Science returning 5 results for the search term (GAMLSS AND "physical activity"),[237,308–311] with the none of these using physical activity as the outcome.

3.1.4 Research questions

I. In a multinational sample, does a measure of overall activity vary between the genders, with boys undertaking more activity, mirroring existing studies?
II. If different distributions are observed between the genders, are they more apparent at moderate and vigorous intensities?

3.2 Methodology

3.2.1 The International Children's Accelerometry Database.

Globally, there is a limited amount of large epidemiological datasets with objectively measured physical activity focussed on representative samples (rather than samples selected to focus on a particular outcome). Further to this there are few with consistent methods extending through the choice of device, methods of processing and constitution of sample collected which would enable comparison between them. The International

Children's Accelerometry Database (ICAD) was established to address some of the issues in comparing physical activity data between studies (See section 2.1 for discussion of this).[259,312] With ICAD providing a harmonised dataset, studies can be directly compared without the need to caveat that the interpretation of 'physical activity' may vary between studies.

3.2.2 Datasets

ICAD includes accelerometry data from 37,827 participants (N=14,232 boys, N=22,803 girls and N=792 with gender unknown) aged between 2.5 and 19.5. This analysis used a subset of the available studies, with selection based on the inclusion of individuals aged between 5 and 18, that the studies were either cross-sectional or the first wave of a longitudinal study of accelerometry and were not primarily focussed an intervention group. The included studies were the Pelotas Birth Cohort (Brazil), National Health and Nutrition Examination Survey (NHANES) (USA), the Avon Longitudinal Study of Parents and Children (ALSPAC) (UK), European Youth Heart Study (EYHS) (Denmark, Estonia, Norway and Portugal), the Kinder-Sportstudie (KISS) (Switzerland) and the Healthy Eating and Play Study (HEAPS)/ Children Living in Active Neighbourhoods Project (CLAN) (Australia) (See Table 3-1).

3.2.3 Variables

Through data cleaning, the dataset was reduced to a selection of variables that encompassed objective measures of physical activity, anthropometric data (height and weight), socio-demographic data (gender, parental education, ethnicity, study location) and variables regarding study design (seasonality).

Following data cleaning a total of 18980 individuals remained in the sample with 885 individuals removed prior to final analysis. Of those removed, 657 were removed due containing no physical activity data, 55 were missing detail on which study they were a part of, 8 were missing detail on their gender and a final 165 were removed for being marked as unreliable, either by the individuals study owners or by ICAD (Detail of missingness by variable in Table S A-2). For those who were marked as having unreliable data, this is mostly likely due to device malfunction with some individuals recording exceedingly high mean daily counts per minute (>5000cpm) or failing to record any activity. Restricting to complete cases for gender, age, BMI, study and parental education left a maximum analytical sample of 15,461 (Detail available in Appendix A).

3.2.3.1 Activity

For all individuals a total count of activity was collected, this is an approximate sum of all the movements recorded by the device. Individuals wore devices for different periods of time, as such a direct comparison of total counts across the recording would give an erroneous interpretation of individual activity. Instead, the total counts were averaged across the duration of the recording to give a mean number of counts per minute (cpm) of recording. As children were instructed to remove the accelerometers at night, primarily due to the discomfort of wearing a device while laying, this gives an approximate cpm for all wakeful activity.

3.2.3.1.1 Activity thresholds.

An issue with total counts is their interpretability beyond an understanding of the value being greater or lesser than another (previously discussed in section 2.2). In most physical activity literature and public health messaging the activity counts are converted into a volume of time between certain cut-points. Given the age range observed in the present study (See section 3.3.1), Evenson cut points are used (*Sedentary < 101cpm ≤ Light <2296cpm ≤ Moderate < 4012cpm ≤ Vigorous*). While there is disagreement in what thresholds should be used to demarcate different intensity thresholds,[274] two commonly used methodologies used in childhood accelerometry measures are the Evenson thresholds[300] and the Pate Thresholds[313] with the former more often used for children of school age, and the later used more often for preschool children. [300,313] Compared to studies using Pate thresholds, Evenson cut points should return greater volumes of light activity, with lower volumes of sedentary and moderate-to-vigorous physical activity.

3.2.3.2 Gender

In the present study gender is treated as a binary measure, as in the harmonized dataset, individual gender is given by boy or girl. Gender is reported at numerous time points throughout the contributing studies and is a mixture of parent and child report. In the harmonisation process conducted by ICAD, parental report at induction was preferentially used with child report used to impute any missing data. Across the contributing studies there is likely some conflation between sex and gender in the respective surveys, but throughout this study the output shall be treated as a binary interpretation of gender.

3.2.3.3 Country

Within this study, each study is represented as the nation from which it was are drawn. Though to varying degrees of success, each study has attempted to be representative of the children within the nation. For instance, while ALSPAC is a sample drawn from one county in the United Kingdom, designed to include all live births within a given year. As such, it should be broadly representative of the region in which it is drawn, but may differ from broader national demographics.[314]

3.2.3.4 Body Mass Index

Discussed further in section 1.1.2.4, though physical activity and exercise are frequently viewed as a causal means of modifying adiposity,[53,315,316] the relationship between the two is far from clear and likely bidirectional.[317,318] In ICAD, the association between BMI and physical activity (total counts) was inconsistent across ages, with no association for individuals up to age 6, but a consistent negative association at ages 7 and greater.[7] As such, BMI is included in adjusted models to account for any potential confounding of outcomes.

Body Mass Index (BMI) values were not precalculated for each individual, instead height and weight were given. These were then used to create a BMI score by dividing weight in kilograms by height in meters squared. Height was recorded at the time of recording for all studies and reported as centimetres in the harmonised ICAD dataset. In the Pelotas study, height was recorded at ages 11 and age 12, in the harmonised dataset the age 12 height was used as it was recorded temporally closer to the accelerometer recording. Weight was recorded in kilograms at the time of recording in all studies except Pelotas. As before, the Pelotas study the recording at age 12 was used in the harmonised dataset. To account for variations in BMI categorisation with age,[147] BMI was converted into an internally calculated gender and age-specific z-score.[319]

3.2.3.5 Parental education level

In studies of childhood physical activity, including those conducted within ICAD,[320] socioeconomic status has been observed to associate with activity patterns.[321] A primary mechanism through which this occurs appears to be due to stratified access to leisure-based physical activity.[322] While resources alter accessibility to childhood sport due to the financial burden of participation,[323] socially stratified access to sport further occurs both within and between communities, as a function of social capital, connectedness, financial inequality.[322] While gender may alter intent to partake in sports and leisure, socioeconomic status compounds this by affecting the opportunities to enact that intent.

As in previous ICAD studies, for the purpose of discerning household SES, parental education was used.[320] Details on both mothers and fathers education was included in all studies except the Pelotas study, for which paternal education was missing. Studies categorised education as "Compulsory Education, some post compulsory education or vocational training, or completed undergraduate or postgraduate education", with the EYHS in Portugal and Norway reporting parental education as a binary outcome of "Up to compulsory school education, or beyond compulsory school education". In data cleaning education was recoded to match the subsets employed in previous analyses of the ICAD dataset.[294] In particular individuals were sorted into whether their parents had remained in schooling up to state minimums or whether parents had received further education.

3.2.3.6 Ethnicity

Across the contributing studies, ethnicity was reported in a mixed manner. The reporting fashions were of the possible formats of "White, or Other", "White, Black, Asian, Mixed, or Other", "White, Black, or Other", or "Non-Hispanic, or Hispanic". As in other studies using ICAD, all datasets with ethnicity information were reduced to the simplest model which was "White or Other". Due to a high level of missingness and being completely absent in the samples from Australia and Switzerland, Ethnicity was only included in sensitivity analyses.

3.2.3.7 Age

Age is recorded in years at the time of activity recording. This was either calculated from the given date of birth and the date of activity recording, or an age is given explicitly by the study at the time of activity recording. Individuals were aged between 4.35 and 18.42 with a mean age of 11.8 years.

3.2.4 Analysis

Initially, the exploration of the differences between groups is through descriptive analysis, both numeric and visual, of the distributions of each outcome (Table 3-1). Subsequently, the GAMLSS package in R,[286,324] was used to investigate the relative distribution and variation in volumes of physical activity by each exposure of investigation. To explore the percentage differences in the mean and variability a normal distribution GAMLSS model was run for each research question. Additionally, to examine differences in the median and skew between subgroups a Box-Cox Cole and Green distribution was used. A Box-Cox transformation transforms skewed data to a normal distribution. The power (λ) required to do is a measure of the non-normality of the underlying data and is reported here as a measure of skewness. This is estimated by maximum likelihood, and varies by the degree of skew, a power of one is required to transform normal data, with values lower than this for increasingly positive skews, and higher for negative skews.[324] Given the transformation of skewness in a Box-Cox, the measure of central tendency is given by the median. However, due to the log function within BCCG, negative and 0 values cannot be passed, thus any 0 values were recoded to 0.001, this was only necessary for measures of moderate and vigorous physical activity (thus also the composite measure of MVPA). This does not alter the output and allows for the maximum possible sample to be included. Further, zeros in these thresholds were seen for almost all countries and in both genders (see Table S A-2).

The initial unadjusted model explored the physical activity outcome (Total counts, time spent in sedentary, light, moderate and vigorous behaviour) and the main exposure of gender. The adjusted model included the additional covariates of nation, parental education, and body mass index (z-score).

Participants with a mean recording length greater than 16 hours (960 minutes) of recording per day were removed for analyses exploring either sedentary or counts per minute. In line with other studies using ICAD, this exclusion threshold was chosen to remove individuals who did not remove their device during sleep.[105,325,326] With sleep being spent sedentary, this would invalidate any comparison based on sedentary activity. Additionally, this would invalidate any comparison of cpm between studies as in other countries this measure is *wakeful* activity rather than *total 24hr* activity. Notably, such a restriction substantially affected the sample composition from the Pelotas Study and KISS (Appendix A). Individuals with more than 16 hours of recording were included in analyses exploring light, moderate and vigorous activity.

GAMLSS requires complete cases for analysis. The sample discussed was restricted to complete cases for physical activity, gender, study, parental education (a binary measure of whether a parent received education beyond compulsory school leaving age) and body mass index (kg/m^2, converted to internally calculated gender and age-specific z-scores[319]) which forms the sample used in the GAMLSS analysis.

To test the robustness of the observed results the unadjusted models for both nation and gender were repeated using the unrestricted dataset (N= 18,980) used in the unadjusted models, with the outcome of which used to infer whether the results could be due to non-random missingness in the analytical sample. Ethnicity and season are not included in the adjusted models due to the missingness observed for these variables (Ethnicity: N= 9,898, 64%; Season: N= 9,604, 62%). Instead, these are included in the sensitivity analyses to explore whether any difference in activity levels between the genders is an artifact of study design. The effect of climate and season was seen in previous ICAD studies, with physical activity seen to be greatest during summer months, when days are longest and when weather was clearer, drier and warmer (up to 20°c).[294,327,328] In the present study, month was recoded into meteorological season, accounting for hemispheric differences. MVPA is additionally broken down into moderate and vigorous intensity activities and analysed separately. To ensure results were not a product of variable wear time, adjusted models were repeated with the inclusion of wear time in sensitivity analysis.

3.3 Results

3.3.1 Sample Characteristics

After data cleaning 15,461 (Boys: 48.3%) individuals had complete data for analysis (Table 3-1). The percentage of boys in studies varies between 45% (Denmark) and 52% (Brazil). Of the nine countries included, four have a larger proportion of boys than girls. The mean age of the sample was 11 years 8 months and ranged from 4.35 to 18.42 years (Table 3-1). As study design is mixed, there was variation in the variance between countries, with birth cohort studies having a narrower spread of ages. The average height (Mean: 148.9cm, SD :15.46) and weight (Mean : 44.96kg, SD : 16.86) fell in normal ranges for the mean age.[329] Boys were taller and heavier than girls in the sample, but the differences were negligible (Δ 2cm & Δ 1kg). Of individuals who reported ethnicity, 70% were white, (70.5% of girls, 69.1% of boys) but this information was missing for Australia and Switzerland. Of those responding, roughly 69% of mothers and fathers had education beyond compulsory level, and this was balanced between the genders, however detail on fathers' education was absent in the Brazilian (Pelotas) study.

Table 3-1: Sample Characteristics, Stratified by gender.

	Overall	Girls	Boys
n	15461	7998	7463
Counts Per Minute* (mean (SD))	588.89 (225.87)	532.91 (200.34)	649.94 (236.11)
MVPA (mean (SD))	52.38 (29.60)	42.94 (23.73)	62.51 (31.84)
Light (mean (SD))	363.36 (78.66)	361.93 (77.74)	364.90 (79.60)
Sedentary* (mean (SD))	357.23 (99.18)	365.86 (99.40)	347.82 (98.08)
Age (mean (SD))	11.71 (2.72)	11.69 (2.71)	11.72 (2.74)
Height (mean (SD))	148.93 (15.46)	147.98 (14.09)	149.94 (16.74)
Weight (mean (SD))	44.96 (16.86)	44.51 (15.55)	45.45 (18.15)
Ethnicity (white) (%)	8366 (69.8)	4345 (70.5)	4021 (69.1)
Mothers Education (Beyond Compulsory) (%)	8933 (58.5)	4672 (59.1)	4261 (57.9)
Fathers Education (Beyond Compulsory) (%)	7614 (62.5)	3953 (62.7)	3661 (62.3)
Country (%)			
Australia	2395 (15.5)	1256 (15.7)	1139 (15.3)
Brazil	455 (2.9)	217 (2.7)	238 (3.2)
Denmark	1491 (9.6)	816 (10.2)	675 (9.0)
Estonia	594 (3.8)	331 (4.1)	263 (3.5)
Norway	367 (2.4)	180 (2.3)	187 (2.5)
Portugal	637 (4.1)	313 (3.9)	324 (4.3)
Switzerland	385 (2.5)	199 (2.5)	186 (2.5)
UK	4785 (30.9)	2511 (31.4)	2274 (30.5)
USA	4352 (28.1)	2175 (27.2)	2177 (29.2)

* = Values are reported after exclusion of individuals with more than 16hrs of recording per day

3.3.2 Counts per minute.

Boys were more active than girls on average, recording over 100cpm more than girls (Boys: 649.94cpm, Girls: 532.91cpm) (Figure 3-1), with estimated values that were 20% greater than that of girls for both the mean and median in the adjusted model (Table 3-2). Boys also observed a broader distribution of values (Figure 3-1), marked by a greater standard deviation (Girls: 200.34, Boys: 236.11), estimated to be 17% larger (Table 3-2). Both genders have moderately positive measures of skew, with the strength of skewness marginally stronger for girls (as noted by a score closer to 1 in Table 3-2, the Box-Cox power centres with 1 being a normal distribution).[237] The results were broadly similar across countries (Figure S A-4), with the exception of Portugal (EYHS) for which little difference between the genders was observed.

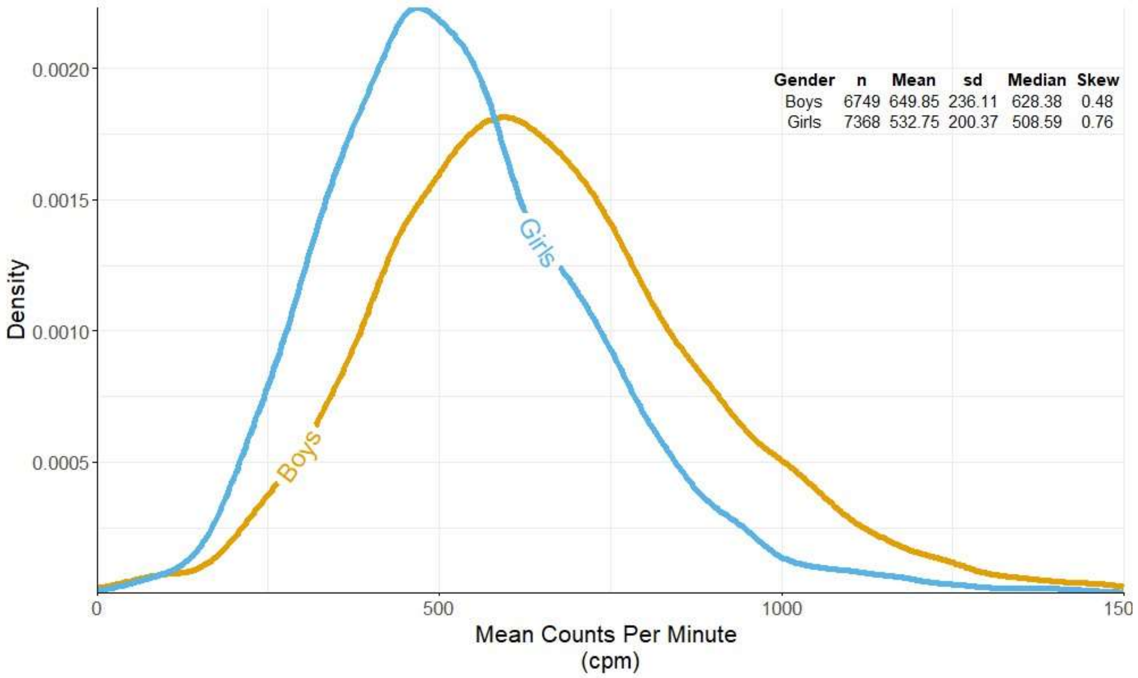


Figure 3-1: Density plot of mean counts per minute by gender, plot is censored at 1,500 cpm to centre of distribution.

Table 3-2: Association between gender and physical activity as measured by counts per minute.

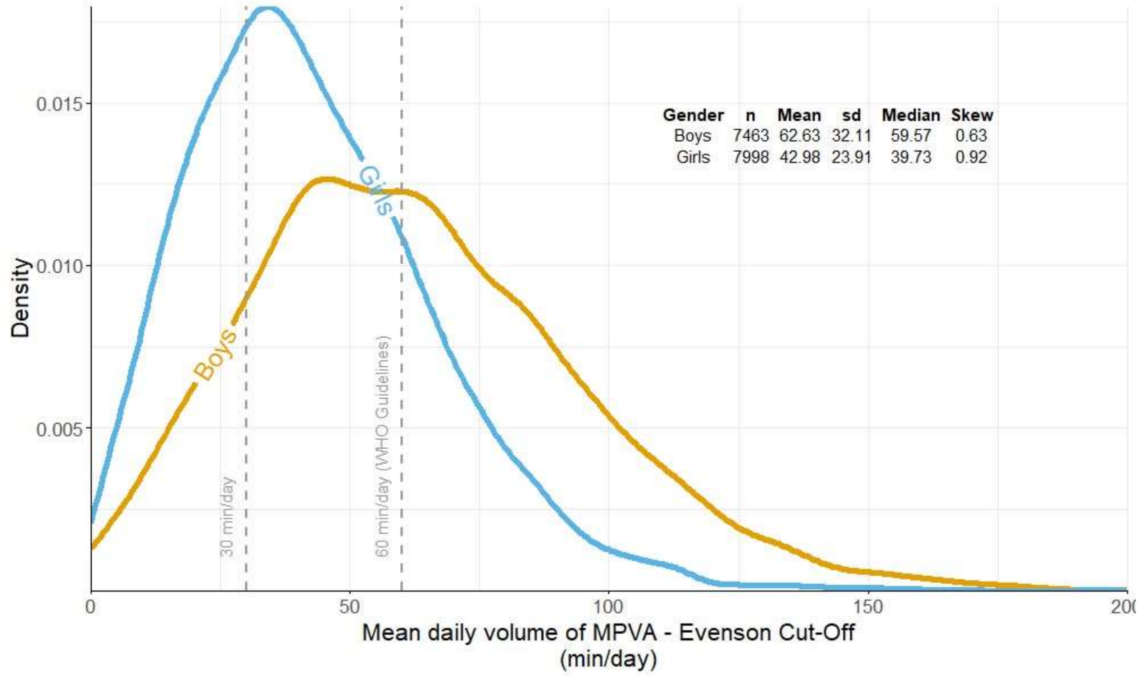
Gender	N (%)	NO distribution		BCCG distribution	
		Mean % Difference (SE)	SD % Difference (SE)	Median % Difference (SE)	Skewness^b
Girls (ref) **Unadjusted**	7377 (52.2)	532.91	200.32	513.31	0.48
Boys **(Unadjusted Difference)**	6763 (47.8)	19.85 (0.62) ***	16.42 (1.26) ***	21.29 (0.67) ***	0.19 (0.03) ***
Boys^a **(Adjusted Difference)**	6763 (47.8)	19.74 (0.58) ***	17.24 (1.19) ***	21.14 (0.63) ***	0.17 (0.03) ***

Note: Differences in mean, variability and skewness estimated by GAMLSS, n=, a = adjusted for parental education, BMI, and country. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

3.3.3 *Moderate to Vigorous Physical Activity (MVPA)*

Boys recorded a greater mean volume of MVPA by Evenson cut points[300] (Girls: 42.94 min/day, Boys: 62.51 min/day) (Figure 3-2). By this measure the mean boy was meeting health guidelines of 60 minutes of MVPA per day, with the mean girl reporting 20 minutes less than the same target per day. Though neither the median boy (59.50 min/day) nor girl (39.71 min/day) met the 60-minute target (Figure 3-2). In the adjusted model, boys recorded a mean volume 37% greater and a median 40% greater than girls (Table 3-3).

Boys showed more variation in their daily volumes of MPVA with a greater standard deviation (Girls: 23.73, Boys: 31.84) (Figure 3-2), with an estimated value 30% greater for boys in the adjusted model (Table 3-3). While both genders had at least one individual who reported no MVPA during the recording period, the single greatest daily volume was observed in girls (Girls: 252.57 min/day, Boys: 235.29 min/day). As with counts per minute, the results were broadly comparable on a country-by-country level. Distributions for both genders were positively skewed, with the strength of skewness slightly stronger for girls than boys (Girls: 0.82, Boys: 0.57) (Figure 3-2).



Gender	n	Mean	sd	Median	Skew
Boys	7463	62.63	32.11	59.57	0.63
Girls	7998	42.98	23.91	39.73	0.92

Figure 3-2: Density plot of moderate-to-vigorous activity as defined by Evenson cut points. Each line representing a gender. Plot is censored at 200 min/day to show centre of distribution. 60 minutes per day and 30 minutes per day are marked by vertical dashed lines.

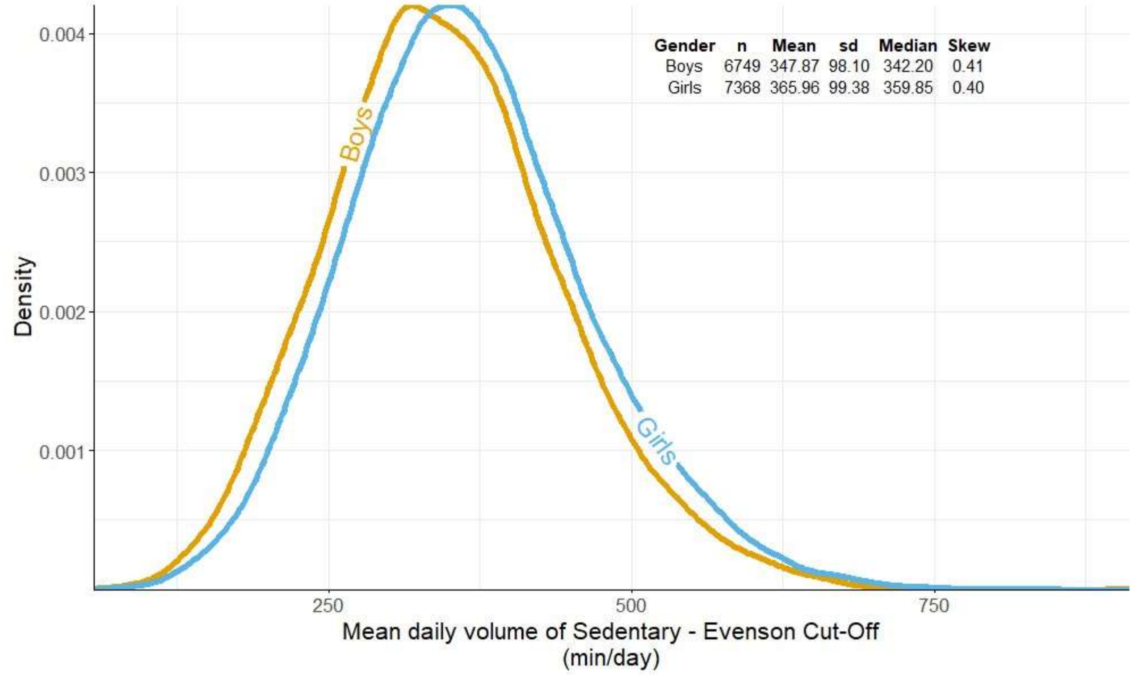
Table 3-3: Association between gender and moderate to vigorous activity as defined by Evenson cut points.

		NO distribution		**BCCG distribution**	
Gender	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
Girls (ref) **Unadjusted**	7996 (51.7)	42.94	23.73	39.81	0.57
Boys **(Unadjusted Difference)**	7457 (48.3)	37.55 (0.85) ***	29.40 (1.13) ***	39.69 (0.97) ***	0.09 (0.02) ***
Boys^a **(Adjusted Difference)**	7457 (48.3)	37.59 (0.79) ***	30.29 (1.14) ***	40.34 (0.92) ***	0.08 (0.02) ***

Note: Differences in mean, variability and skewness estimated by GAMLSS, n=, a = adjusted for parental education, BMI, and country. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

3.3.4 Sedentary activity

Exploring sedentary behaviour, boys and girls had similar distributions of activity (Figure 3-3). Both genders had comparable peak volumes of sedentary activity at approximately six hours per day, with girls returning a marginally higher volume (Girls: 368.74min/day, Boys: 350.17min/day) (Table 3-4, Figure 3-3). The median volume was six minutes less than the mean for both genders, with the scale of difference approximately 5% for both measures of the average (Table 3-4). Standard deviations for the two genders were closely aligned (Girls: 98.79, Boys: 97.92) with an estimated difference of 1% (Table 3-4) in the adjusted model. Both genders observed a weak positive skew, but there was no difference in skewness between the genders in either the unadjusted or adjusted model (Table 3-4).Within each individual nation, the observed patterns of sedentary activity for each gender was broadly similar (Figure S A-6).



Gender	n	Mean	sd	Median	Skew
Boys	6749	347.87	98.10	342.20	0.41
Girls	7368	365.96	99.38	359.85	0.40

Figure 3-3: Density plot of the mean volume of sedentary activity as defined by Evenson cut points, presented for each gender. Exclusion criteria are as outlined in section 3.2.4

Table 3-4: Association between gender and sedentary activity as defined by Evenson cut points.

		NO distribution		**BCCG distribution**	
Gender	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^b**
Girls (ref) **Unadjusted**	7377 (52.2)	365.86	99.39	359.64	0.54
Boys **(Unadjusted Difference)**	6763 (47.8)	-5.01 (0.46) ***	-1.34 (1.19)	-5.15 (0.51) ***	0.01 (0.05)
Boys^a **(Adjusted Difference)**	6763 (47.8)	-5.04 (0.44) ***	-1.58 (1.19)	-5.18 (0.458 ***	-0.01 (0.05)

Note: Differences in mean, variability and skewness estimated by GAMLSS, n=, a = adjusted for parental education, BMI, and country. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

3.3.5 Light activity

In addition to observations of sedentary behaviour, limited differences in distributions of light activity were observed between the genders (Figure 3-4). Both genders recorded approximately 6hrs of light activity per day, with boys recording an additional three minutes of light activity compared to girls (Girls: 361.93 min/day, Boys: 364.90 min/day) (Figure 3-4), estimated to be 1% higher in the adjusted model (Table 3-5). The peak densities were similar for both, with standard deviations closely aligned (Girls: 78.74, Boys: 79.60), with the deviation for boys estimated to be 3% higher (Table 3-5). Both appeared relatively normally distributed, with low, negative measures of skewness for boys and girls (Girls: -0.21, Boys: -0.24) (Table S A-6). Within each individual nation, the observed patterns of light activity for each gender are broadly similar (Figure S A-7).

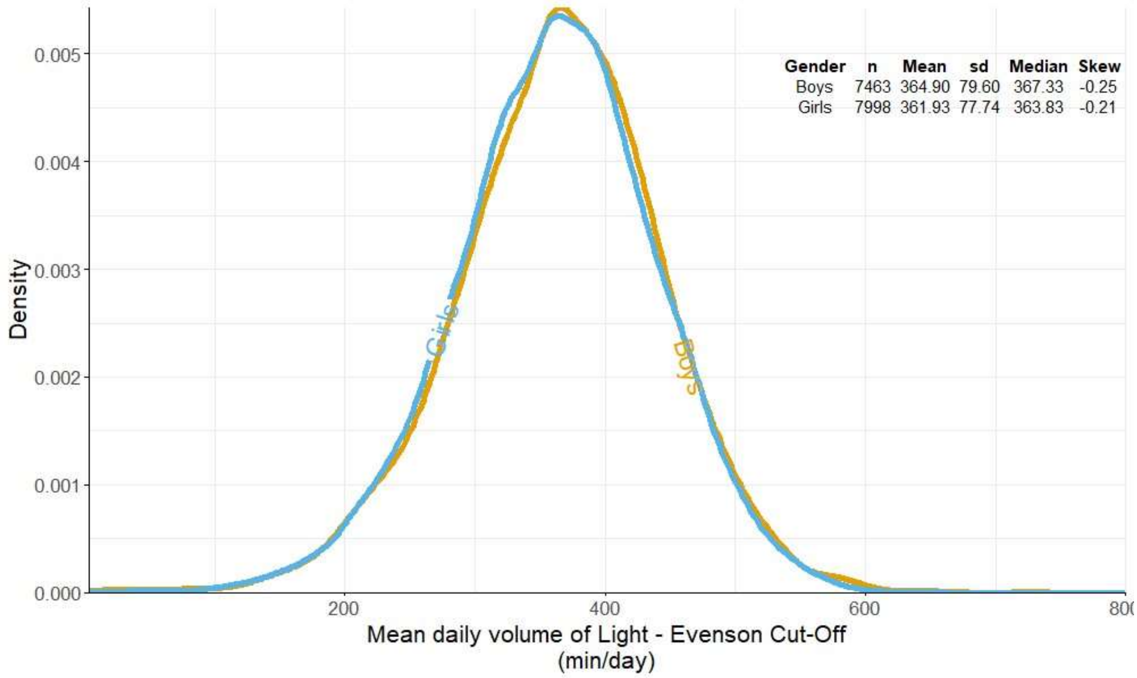


Figure 3-4: Density plot of light activity as defined by Evenson cut points. Each line representing a gender.

Table 3-5: Association between gender and light activity as defined by Evenson cut points.

Gender	N (%)	NO distribution Mean % Difference (SE)	SD % Difference (SE)	BCCG distribution Median % Difference (SE)	Skewness[b]
Girls (ref) **Unadjusted**	7998 (51.7)	361.93	77.73	364.43	1.29
Boys **(Unadjusted Difference)**	7463 (48.3)	0.82 (0.34) *	2.36 (1.14) *	0.90 (0.36) *	0.03 (0.05)
Boys[a] **(Adjusted Difference)**	7463 (48.3)	0.88 (0.33) **	3.26 (1.14) **	0.87 (0.35) *	-0.02 (0.06)

Note: Differences in mean, variability and skewness estimated by GAMLSS, n=, a = adjusted for parental education, BMI, and country. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

3.3.6 Sensitivity analysis

Repeating the base model of physical activity being a function of gender with the unrestricted dataset, no meaningful difference in result was observed with gender (See Table S A-3, Table S A-4, Table S A-5, Table S A-6). Adjusted models additionally including either season or ethnicity did not observe a change in effect size for gender at any intensity (See Models adjusted for season or for ethnicity.

Table S A-7, Table S A-8, Table S A-9, Table S A-13). Adjusting for wear time did not lead to any meaningful differences in the model estimates (See Table S A-10). Separating MVPA into moderate and vigorous intensity activity resulted in similar effects, that were larger for vigorous activities (Table S A-11 & Table S A-12).

3.4 Discussion

3.4.1 Summary of findings.

For both counts per minute and volumes of moderate-to-vigorous activity boys recorded a greater mean value as well as greater variability. While the spread of individuals was larger for boys it was less skewed. These observations were mirrored when looking at moderate and vigorous activity separately. Thus, while boys clustered less around a particular volume of activity, the spread was more even between individuals doing more or less activity than the mean. More equality amongst girls at a lower mean volume implied that few girls in this sample were doing large amounts of MVPA, resulting in a narrow spread of girls centred around median volumes of MVPA derived from lifestyle activities.

In contrast, for both sedentary and light activity, the differences between the genders were marginal, with girls reporting an additional 18 minutes of sedentary time per day and 3 additional minutes of light activity. Neither the distribution nor spread of individuals varied between the genders, with both slightly positively skewed to similar extents. As the time spent at these intensities accounted for most of the waking hours, it indicates that the differences in overall activity (cpm) were driven by a small subset of daily behaviours in moderate to vigorous thresholds.

3.4.2 Differences in distributions amongst boys and girls.

Mirroring previous studies, boys and girls differed in their mean activity count and volume of MVPA.[7,8,293–297] However, the lack of difference in the volume of light activity implies that the difference between boys and girls in their activity is less due to ‘every day' activities that characterises the light intensity spectrum, but instead being driven by changes at the upper end of the spectrum of intensities, which in context of the included populations would likely align with sports and active play.[302,304,305]

Adding to the existing body of research is a quantification of the difference in the distribution. Namely that a higher mean volume of MVPA for boys was observed alongside a higher standard deviation. Volumes of MVPA were less variable in girls, but clustered around a lower value. A possible explanation of this is that boys and girls were doing similar volumes of compulsory sport (i.e. physical education classes) (In Figure 3-2 the volume of MVPA at which the peak density is observed is relatively close between boys and girls), but a larger proportion of boys were undertaking additional leisure-time activity. If that is the case, then increasing opportunities for leisure-time activity for girls may help to reduce differences between boys and girls. However, doing so without centring the interests of those less active[330] may inadvertently act to increase the inequality within girls.

When interpreting differences between the genders in mean volumes of activity, changes were not driven by the whole population, but instead driven by the subset undertaking additional activity. Further, this may explain why boys were less positively skewed for measures of MVPA despite greater variation. The larger subset of boys undertaking near daily leisure-time sports or active play for at least an hour per day on top of their other activities provided more balance to the distribution. Despite the limitations of applying a threshold to a continuous outcome, examining the proportion of individuals meeting 60min/day guidelines may do a better job of capturing this inequality than a measure of the mean volume.

3.4.3 Variation in effects between contributing studies.

Despite differing socio-cultural and political perspectives on youth physical activity, apart from the Portuguese study, all of the other contributing studies observed similar trends in activity between boys and girls (Figure S A-4). While some of this could be due to limitations with accelerometery (See section 3.4.5 below for a broader discussion), it leaves an effect of gender on activity that is stable across the selection of studies. These studies draw from nations that differ in their attitudes and policies to youth activity,[104] and while these differences lead to whole population differences in activity (See Chapter 4), the inequality between boys and girls persists (Figure S A-4). As such, there appears to be a conserved cultural trend amongst these predominantly European or English-speaking nations that makes boys more likley to partake in moderate-to-vigorous activities.

A lack of opportunities for sport and active play for girls could partially underlie the disparity in MVPA. Accordingly, within the UK and other nations interventions have aimed to increase the opportunities for girls to be active with other girls.[291] However, if the present divide is instead a product of gender stratified cultural perspectives on active play and sport,[331] it could be that providing additional opportunities for sport in childhood would widen this disparity, as it could offer boys even more opportunities to be active without tackling the underlying socio-cultural reasons for lower uptake by girls.[332,333] As such, to move the activity pattern of girls towards that of boys, it may be necessary to reframe how activity and sport is conceptualised for girls, which may necessitate an improved socio-cultural perspective on sport and physical activity.[331]

Amongst these nations, adults appear to be are relatively inactive (adherence to WHO recommendation appear higher amongst adults but target volumes are less than half those of children).[94,113] Globally, men seem to be more active than women,[94,113] with evidence amongst American[334], Australian[335] ,British[336], Brazilian[285], Norwegian[337], Portugese[338] and Swiss[339] adults observing a similar activity inequality between men and women. A relative lack of women role models has been proposed to underlie a perception that sports and being physically activity is predominantly a male activity.[331] However, this lack of role model extends beyond the public sphere and into the familial and social networks of girls. With men often being more active, and particular doing so in the leisure time activities[340] that are more readily recounted by children,[341] this could act to further reduce develop the gendered perspective toward activity.

While almost all countries show similar gender differences, Portugal did not have as much of a gender divide in total activity (cpm) as other nations do (Figure S A-4). Within this sample boys were less active when compared to other constituent studies than girls, with Portuguese boys ranked 8th (of 8) in median counts per minute compared to 5th for Portuguese girls. While this could be a result of sampling, confounded by sampling from an isolated subset of the Portuguese population on the island of Madeira,[299] the underlying limited differences remain a contrasting observation. By measures of GDP per capita, Portugal ranks second lowest of all nations included in this study.[342] If, as proposed, differences between the genders were due to sport and active play, reduced financial resources at an individual and state level may balance activity levels by restricting access for all individuals.[343]

3.4.4 Strengths

This study has leant support for the need to explore physical activity as a broad concept, incorporating physical activity across the intensity spectrum. Consistent with previous research, [7,8,293–297] this study found support for previously observed differences between the genders and their volumes of physical activity. With the added interpretation of gender associating with physical activity to differing degrees dependent on the intensity threshold.

Additionally, the present approach has highlighted the value of incorporating measures of the distribution into analyses of health behaviours. In particular, the GAMLSS approach used here highlights that there is a difference in distributions not highlighted by traditional regressions, which helps elucidate drivers of difference between the genders.

While limitations to the study sample are discussed below, ICAD is a suitable dataset to conduct a proprietary multi-national study that explores physical activity as a continuous, objective measure. A consistent limitation in physical activity research is the lack of comparability between studies which ICAD largely avoids by having a consistent means of analysis through the harmonisation process.[259] Further, the minimum sample size of 14,140 included in the most stringently restricted adjusted models is extensive for an accelerometer study.

3.4.5 Limitations

While GAMLSS offers an ability to explore the distribution which is not possible in traditional linear regression, there are some limitations to this approach. Firstly, the requirement of complete cases for a Box-Cox Cole and Green transformation restricts the sample size throughout. This is noticeable in both the adjusted model, and in the sensitivity analyses, where the loss in sample size was large with the inclusion of ethnicity and season. While this presents a risk that the data is not missing at random once such a restriction is placed, no notable changes in the results were seen during sensitivity analyses.

Discussed in more detail in section 2.2.2.1, Accelerometry is limited in its ability to measure resistance-based activities, and activities like cycling, where motion is in a plane not measured by the device which may underestimate physical activity levels. Finally, most of the studies included in ICAD instructed participants to remove the device at night (being waist worn the device could be uncomfortable during sleep).[105,325,326] This results in activity profiles that represent daytime activities, and cannot be suitably used to explore isotemporal substitution, as such, partaking in more MVPA in this study does need not come at the expense of time in another threshold.[230]

While the effect of selective non-wear was assessed through sensitivity analysis (See Table S A-10), this may not fully account for periods of non-wear not being randomly distributed across all behaviours. Although typically instructed to only remove the device when going to bed or when entering water (including swimming), studies often report children removing the device when playing contact sports.[344,345] In the case of the later, this may result accelerometery underestimating the overall volumes of activity, particularly MVPA. For the present results, the likely effect of selective non-wear would be to under account for boys' activity if the assumption that the differences between boys and girls are due to leisure time sport and active play. As such, while this limitation may alter the absolute values of the distribution, but it would likely increase the scale of difference between boys and girls rather than reduce it.

Composite of studies undertaken at different times present an issue of comparability between different iterations of the accelerometry technology. Namely, early accelerometers reported activity over a 60 second window, with newer devices reporting at a window length between 1 and 15 seconds. To ensure backward compatibility, recordings from newer devices are re-processed at the resolution of the oldest devices. Thus, the comparability between studies has come at the cost of some resolution. The limitation introduced by this is a reduced ability to discern sporadic and intermittent behaviour. For instance, if a child were to sprint at maximum effort for 10 seconds and rest for the subsequent 50 seconds, the reported intensity is averaged across the minute, giving an intensity that neither represents the most intensive or sedentary time in that minute.

It is necessary to note that while ICAD offers the broadest dataset available, it represents a narrow band of populations and cultures. As the sample draws from countries with broadly similar political, economic and cultural practices, which can be due to cultural descent or by diffusion due to spatial proximity the nations included here are not truly independent from each other.[247] As such any consistency in results observed here reflects only the studies included.

Discussed further in Chapter 4, each study varies in how well it represents the nation from which it draws. As such, if there was regional variation in activity patterns this could alter results. For instance, the results from Madeira may not be representative of broader trends in activity of the Portuguese mainland. Undertaken in 2006, six years after the EYHS study included here, a study of self-reported activity amongst mainland Portuguese youth did observe boys to undertake more activity than girls.[338] For most studies here the direction of difference mirrors observations in the broader international literature, so is likely to be similar between both the study and the nations they draw from. Harder to comment on is potential differences in distribution between the study and nation due to the lack of research that this chapter seeks to begin to address.

3.4.6 Conclusions and links to other chapters.

In addition to inequality between girls and boys, using a GAMLSS approach observed sizable and variable levels of inequality within each gender. Differences in overall activity (cpm) were mainly driven by the upper end of the activity spectrum; both the higher intensity activities (MVPA) and the most active individuals. Boys were more active on average, but this is due to a sizable subset of boys undertaking high volumes of MVPA, rather than all boys doing a small amount more than girls. In intensities more typified by activities of daily life, there was minimal differences between boys in girls in any aspect of the distribution. Where focus is placed on addressing differences in MVPA, attention should be placed on the full distribution of individuals, as an intervention may narrow the difference between boys and girls yet, by focussing this change on a subset of individuals, it may exacerbate the inequality within boys and girls. For equitable change in children's activity, interventions should aim to benefit those in the lowest quantiles as effectively as the highest.

Expanding from difference between boys and girls, Chapter 4 continues the approach of this analysis to examine the differences in the distributions amongst the included studies in ICAD. To expand on the cross-cultural differences, Chapter 6 examines physical activity patterns amongst BaYaka children and compares them to a later wave of NHANES and the British MCS. In doing so, Chapter 6 also examines if gender is equally associated with activity in a hunter-gatherer population, with results that do not match those observed here. The wider relevance of understanding physical activity due to its association with health is included in section 1.1. The present study employs accelerometery to measure activity, but a wider discussion on the relative strengths and weaknesses in methods of objective physical activity measurement are included in sections 2.1, which explores why different techniques may come to different conclusions.

Chapter 4 Cross-national comparisons of physical activity in the International Children's Accelerometry Database.

Main Objective: To examine differences in the distribution of activity in a multinational sample of children's accelerometer data.

Background: Cross-national studies of physical activity help highlight how nations vary in their uptake of physical activity. However, research has largely focussed on summary measures. The present research attempts to address this gap by examining the full distribution of activity across all intensities of activity.

Methods: Using the International Children's Accelerometry Database (ICAD), the association between nation of study and the distribution of objectively measured physical activity is examined. Including 15,461 individuals (Boys: 48.3%) from 9 countries, Generalised Models of Location Shape and Scale (GAMLSS) are employed to assess difference in the distribution for each threshold of activity (Sedentary, Light, and Moderate-to-Vigorous (MVPA)) and a summary measure (Counts per Minute (cpm)).

Results: Cross-sample differences were observed in all measures of activity. For sedentary behaviour, the samples with the highest mean volumes (Danish: 389min/day and US: 385min/day), also observed the greatest standard deviations (Danish: 121min/day and US: 108min/day). Whereas, for the most active thresholds, higher average volumes did not track with increasing deviations. Samples were most skewed in the most intensive thresholds, with distributions approaching normality for light and sedentary activity.

Conclusions: Distributions of activity differed between the contributing studies with greater differences observed at greater intensities of movement. Incorporating measures of the full distribution highlighted that populations that were more active were no more likely to have an equitable distribution of these activities. However, traits of a studies distribution did track across activity measures, with a population that was less variable in one measure was likely to be less variable in another.

4.1 Introduction

4.1.1 Cross-national comparisons of physical activity in youth.

Studying patterns of physical activity at a national level should make evident the factors that are associated with differing activity levels within that population,[346] but may fail to identify factors that are ubiquitous within that group.[114,239,347] These may include factors which influence the entire population of interest, such as those influenced by national policy.[239] A cross-national approach to compare activity patterns could highlight how countries vary in their burden of physical inactivity.[116]

There is a well-established interest in understanding cross-national variation in youth activity from a global health perspective. Notably, the World Health Organization maintains a Global Physical Activity Report Card that grades nations on both the self-reported levels of activity of their populace and their policies and practices for promoting activity.[104] However, in developing an understanding of differences between youth samples, reports are primarily built upon studies of the mean. As discussed in Chapter 3, very little research has been undertaken to examine differences between the distributions of individuals. Chaput et al., (2018) provides one of the only identified studies exploring the variation in activity inequality in a sample of children.[348] Notably, this study did not take into account the full spectrum of activity. However, this study and that undertaken in Chapter 3 highlight the potential for factors to both affect the difference between groups and within groups.

4.1.2 Nation and its association variability in physical activity.

Most nations share an interest in increasing the physical activity of their populaces, however, how they go about doing this varies. For children, through policy governments can target activity within schools, the built environment or the access to leisure-time activity.[104,349,350] A factor associated with the difference in activity levels between nations appears to be the volume of lifestyle activity. Through national policy, where a greater volume of activity is part of the mandatory curriculum, or where policy facilitates active transport, the population may be expected to undertake a greater minimum volume of activity, partially due to a less variable response to the policy.[116,350] In contrast, where activity interventions target leisure-time activity, more variability might be expected as individuals can choose their own activity level or have their choices constrained [301–305] (Figure 4-1). This may be more apparent for intensive activities, such as those provided by organised sports and clubs, as individual participation will be driven by access, resources, and interest, which are not distributed uniformly across the population.

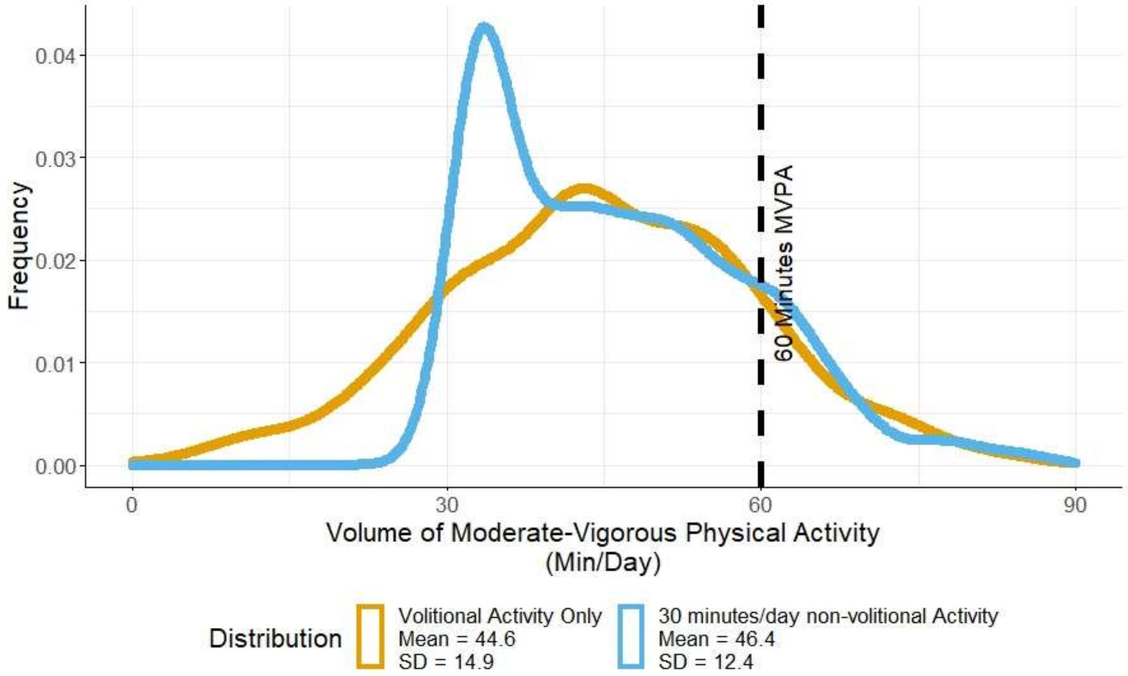


Figure 4-1: Density plot showing two hypothetical settings of 1000 individuals both centred at 45min of activity a day. The orange line represents individuals who are free to choose their own activity levels, a second where all individuals must undertake at least 30minutes of MVPA per day. Both modelled random distributions have the same parameters, but in the second, all individuals with activity less than 30min/day were assigned a value of 30.

Beyond in-school sports classes, the structure of learning could have key impacts. Physical activity appears to peak between ages 5 and 7 in the ICAD dataset,[7,8] which roughly approximates with the transition from play based learning (i.e. Kindergarten in USA & Germany, Nursery in the UK, écoles maternelles in France, etc.) to academic learning (i.e. first grade in the USA, reception in the UK, cours préparatoire in France, etc.). At this transition less activity occurs through the school setting, leaving greater influence to leisure-time activity. In a Norwegian study of 294 children studied longitudinally from ages 3 through to age 9, total activity (counts per minute) peaked at age 5 (children begin formal education in the year they turn 6 in Norway).[351] However, MVPA peaked at a later age, up to age 8, supporting a view that activity of daily life is influencing activity profiles until formal education begins, subsequent to which, leisure-time activity becomes more influential in the development of activity profiles.

In Denmark a practice of udeskole is implemented (direct translation: outdoor school), which takes children out of class and into the surrounding areas, whether that is in green spaces or within cultural institutions like museums.[352] Compared to normal school days udeskole days were associated with 12% greater volumes of physical activity, which was largely driven by an exchange of time in sedentary activity for time in light activity.[353] This supports a view that low levels of childhood physical activity may be due to the sedentary behaviour that a classroom setting encourages. Yet, while changes from this norm can facilitate higher physical activity, the change here came though light activity, which would not be registered in studies solely examining MVPA.

Mode of transport may play a significant role in children's activity, with uptake of active transport to schools associated with an increased likelihood of meeting physical activity targets.[354] Given the relevance to public health, increasing active transport is a target for most governments.[355] However, the progress made towards this is variable and dependent on the built environment. In a self-report study of the proportion of children using active transport, there was observed to be a large amount of variation between nations which was not explained by HDI.[350] Though of similar economic development, the Netherlands, Denmark and Finland are seen to have a good uptake of active transport to school (over 60% of students) with Australia, the USA and the UK having a poor uptake (below 40%). Where active infrastructure is a public good (i.e. all children who live near the infrastructure can use it) it may offer a means to level activity patterns between different socio-economic groups.[321,356] As such, in regions with more developed infrastructure for active transport there may be less disparity between individuals in the amount of activity they undertake.

While active transport can act as a means of levelling the exposure to total activity between socio-economic groups, it may have differing effects on different intensities of activity. Compared to organised sport, active transport is likely to occupy less intensive thresholds. As such the difference between an individual undertaking more active transport and one undertaking more organised sport is likely to be smaller with a measure of total activity, such as cpm, than an intensity specific measure such as MVPA.[357] As such it may be that a wider distribution around the mean is seen in intensity-specific activity counts.

Expanding on the potential variability within thresholds, it may be that within MVPA, there is a greater variation around the mean and a greater potential for the data to be positively skewed. While it is unlikely that any child is completely inactive, it is possible that none of their activity comes from the highest intensities. For an accelerometer, MVPA is generally consistent of sport like activities such as active play or sport. [301–305] As such where there is greater variance in access to sport the greater the likley difference in the volume of MVPA.

One potential driver of variance cross-nationally is the relative focus and funding for competitive and high performance elite sport at youth levels (i.e. individuals pursuing success in national or international competitions).[358] Such a focus could cause a long tail in the distribution of activity patterns with a small subset of individuals partaking in large volumes of activity. While most nations have an interest in elite youth sport, the infrastructure and scale can very between nations.[104,358] Potentially complicating this further is sports role in the access to education in nations, namely the USA, in which 39% of US high school students stated that they were pursuing an athletic scholarship (1-2% of US college students receive such a scholarship).[359] With elite levels of youth sport offering accessible pathways to further education, the proportion of individuals prioritising sports and the requisite training levels associated with such achievement,[360] may add further skew to the distribution.

4.1.3 Cross-National Variation in the International Children's Accelerometry Database

Some research into cross-national differences in objectively measured physical activity in youth has been undertaken using data from the International Children’s Accelerometry Database (ICAD). There was significant variations in objectively measured total physical activity (counts per day) between studies, with the variation between studies increasing with age.[7] There was some regional differentiation with samples from northern European studies having activity levels in the top half of studies. Looking within Europe, children from northern Europe were more likely to meet activity guidelines of 60min/day of MVPA than individuals in central Europe (0.90 OR) or southern Europe (0.65), however the effect was smaller for adolescents (Central Europe OR:0.93, Southern Europe OR: 0.69).[8]

In other studies conducted in the same nations as those contributing to the ICAD, amongst pre-school aged children (ages 3-4 years), studies undertaken in the US (Mean = 98min/day) and UK (Mean = 85min/day) observed higher volumes of MVPA than studies undertaken in Switzerland (Mean = 65min/day) or Belgium (Mean = 80min/day).[294] The authors posit that this may be due to differing childcare practices, with the three European nations showing similar profiles of activity across the day, with the US showing a more defined bi-modal distribution of physical activity.

In the PISA study (a large cross-sectional study of self-reported physical activity in adolescence) a large disparity in the amount of activity engaged in between the contributing ICAD nations was observed.[116] Within this sample the USA had the highest reported number of hours of physical education and the most days of the week with vigorous activity but the greatest variation for each. Conversely, Brazilian adolescents had the lowest value for both schooling and vigorous activity yet the second highest variation for each, behind only the USA. In Europe, adolescents from Norway and Denmark reported engaging in moderate or vigorous activities on more days of the week than the UK and Portugal despite having less hours of school per week committed to physical education. However, the amount of variation observed was middling for both Norway and Denmark. Further, using self-reported activity may lead to biased accounts based on more memorable activities.[269]

Focussed on objective measures of MVPA and sedentary behaviour, the previously mentioned study by Chaput et al., (2018) included studies from Australia, Brazil, (mainland) Portugal, the UK and the USA.[348] Of these, there was greater equality in MVPA amongst the most active sample of the UK and Australian sample. Amongst the remaining three, Brazil was the most unequal despite the third highest volumes of activity (of five). Despite greater volumes of sedentary behaviour, there was greater equality at this intensity across the five nations. While the most inactive nation (Portugal) was the most equal for measures of sedentary activity, differences between studies were marginal with no notable correlation between the mean and Gini for sedentary behaviour.

Collectively, few cross-national studies have employed objective measures of activity and done so at scale. Of those that have, fewer still have examined all intensities of activity (sedentary, light and moderate-to-vigorous intensity activity) and a measure of overall activity (cpm). None of which have sought to examine difference in multiple parameters of the distribution (central tendency, variation and skewness) using an approach such as GAMLSS. This chapter aims to address that gap.

4.1.4 Research questions

I. Across all intensities of activity, do distributions of physical activity vary between nations?

II. Do patterns of variation mirror observations of gender, with greater differences in MVPA rather than sedentary and light intensities of activity?

4.2 Methodology

4.2.1 Datasets

This analysis employs a similar methodology to Chapter 3. As before, the present analysis includes individuals who were aged between 5 and 18, were part of studies that were either cross-sectional or the first wave of a longitudinal study of accelerometry and were not primarily focussed on an intervention group. The included studies were the Pelotas Birth Cohort (Brazil), National Health and Nutrition Examination Survey (NHANES) (USA), the Avon Longitudinal Study of Parents and Children (ALSPAC) (UK), European Youth Heart Study (EYHS) (Denmark, Estonia, Norway and Portugal), the Kinder-Sportstudie (KISS) (Switzerland) and the Healthy Eating and Play Study (HEAPS)/ Children Living in Active Neighbourhoods Project (CLAN) (Australia) (See Table 2-1). A more detailed discussion of the ICAD dataset employed can be found in Appendix A.

4.2.2 Variables

As employed in Chapter 3, the dataset was reduced to a selection of variables that encompassed objective measures of physical activity, anthropometric data (height and weight), socio-demographic data (gender, parental education, ethnicity, study location, age) and variables regarding study design (seasonality). Variables were recoded to be more comprehensible in later analyses, (detail available in 3.2.3). As before, Evenson cut points are used to delineate differing intensity thresholds,[300] with counts per minute (cpm) used as a measure of total activity across all intensities.

Following data cleaning a total of 18980 individuals remained in the unrestricted sample with 885 individuals removed prior to final analysis. Of those removed, 657 were removed due to containing no physical activity data, 55 were missing detail on which study they were a part of, 8 were missing detail on their gender and a final 165 were removed for being marked as unreliable, either by the individuals study owners or by ICAD (Detail of missingness by variable in 0). For those who were marked as having unreliable data, this is mostly likely due to device malfunction with some individuals recording exceedingly high mean daily counts per minute (>5000cpm), or failing to record any activity. Restricting to complete cases for gender, age, BMI, study and parental education left a maximum analytical sample of 15,438 (Detail available in Appendix B).

4.2.3 Analysis

Initially, the exploration of the differences between groups is through descriptive analysis, of the distributions of each outcome. Subsequently, the GAMLSS package in R,[286,324] was used to investigate the relative distribution and variation in volumes of physical activity by each exposure of investigation. A normal distribution GAMLSS model was run to explore the percentage differences in the mean and variability, with a Box-Cox Cole and Green (BCCG) distribution used to examine differences in the median and skew. Detail on a Box-Cox Cole and Green transformation is available in section 3.2.4.

To address the research questions, the initial unadjusted model explored the physical activity outcome (Total counts, time spent in sedentary, light, moderate and vigorous behaviour) and the central grouping variable of the nation of study. The UK is used throughout as the reference category in the analysis, this choice was made as the UK is used as a comparison in the later BaYaka chapters, and unlike the US, observed middling values for most outcome measures. The adjusted model includes the covariates of gender (reference = girl), age (centred), BMI (included as a Z score, standardised by age to the nearest whole year, and by gender) and parental education (reference = neither parent in receipt of beyond compulsory education). Restricting the sample to complete cases of season and ethnicity notably reduced the sample size, thus these were included in sensitivity analysis. As in Chapter 3, participants with a mean recording length greater than 16 hours (960 minutes) of recording per day were removed for analyses exploring either sedentary or counts per minute. This restriction affected the sample composition from the Pelotas Study and KISS (Figure S A-2). Individuals with more than 16 hours of recording were included in analyses exploring light, moderate and vigorous activity.

In addition to complete cases, due to the log function in a BCCG transformation, GAMLSS cannot pass zeros. To address this, any individual who recorded zero minutes per day in a particular threshold (observed only in moderate, vigorous and MVPA) was recoded to 0.001 minutes per day.

4.2.3.1 Sensitivity Analysis

To test the robustness of the results, and to ensure this was not a function of non-random missingness, sensitivity analyses were conducted. This involved repeating the unadjusted model with the dataset only restricted to complete cases for activity and gender. Ethnicity (white/other) and season were only available in a subset of individuals (Ethnicity: N=

9,898, 64%; Season: N= 9,604, 62%); factors were adjusted for in additional sensitivity analysis of these countries. MVPA is additionally broken down into moderate and vigorous intensity activities and analysed separately. To ensure results were not a product of variable wear time, adjusted models were repeated with the inclusion of wear time in sensitivity analysis.

4.3 Results

4.3.1 Sample Characteristics.

After data cleaning and restriction to complete cases, a maximum of 15,438 individuals remained in the data set (Table 4-1). Of these, 48.3% (n=7449) were boys. Gender split varies between countries, with the percentage of boys between 45% (Denmark) and 52.2% (Brazil). The mean age of the sample was 11 years 8 months. As study design is mixed, this varied between studies, from 9 to 13, with birth cohort groups showing a narrow spread of ages. The average height (Mean : 148.95cm, SD :15.45) and weight (Mean : 44.98kg, SD : 16.87) fall in normal ranges for the mean age and track age across studies.[361]. Boys were both slightly taller and heavier than girls in the sample, but the differences were negligible (Δ 2cm & Δ 1kg). Of those responding, roughly 60% of mothers and fathers had education beyond compulsory level, and this was balanced between the genders, however detail on fathers' education is absent in the Brazilian (Pelotas) study.

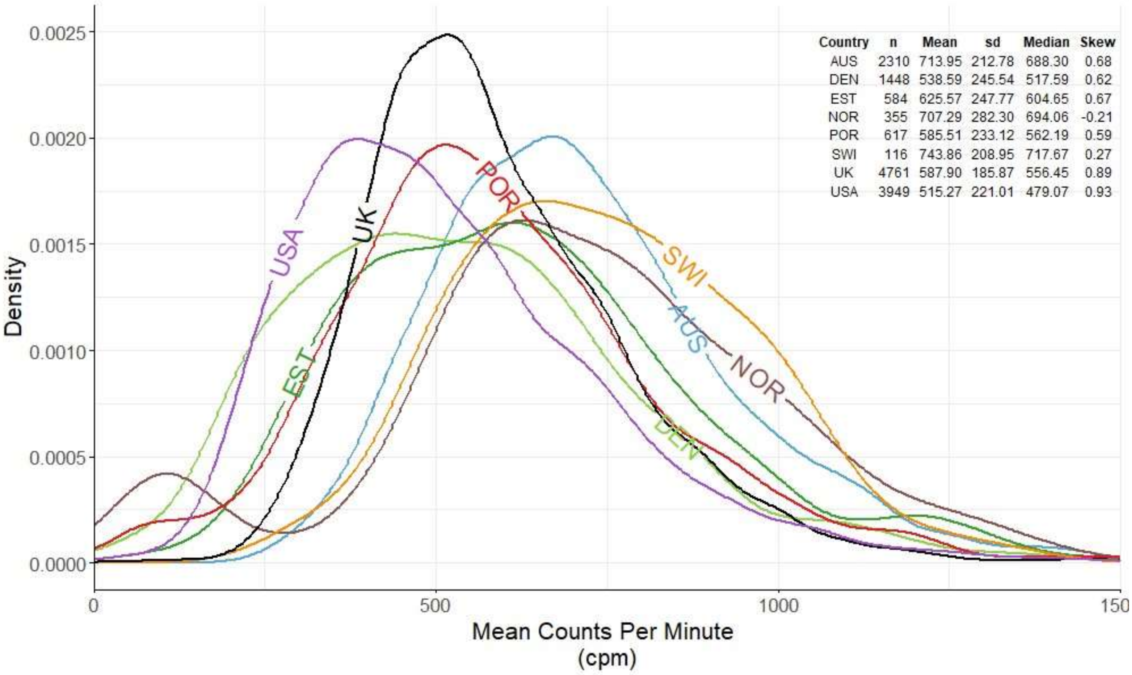
Table 4-1: Sample Characteristics, stratified by country.

	Overall	Australia	Brazil	Denmark	Estonia	Norway	Portugal	Switzerland	UK	USA
n	15438	2372	455	1491	594	367	637	385	4785	4352
Gender (Boy) (%)	7449 (48.3)	1125 (47.4)	238 (52.3)	675 (45.3)	263 (44.3)	187 (51.0)	324 (50.9)	186 (48.3)	2274 (47.5)	2177 (50.0)
Age (mean (SD))	11.71 (2.72)	9.59 (2.61)	13.34 (0.31)	12.20 (2.94)	12.29 (2.99)	9.68 (0.33)	11.77 (2.83)	9.32 (2.12)	11.81 (0.23)	12.70 (3.47)
Height (cm) (mean (SD))	148.95 (15.45)	137.32 (16.21)	158.00 (8.40)	152.54 (16.73)	151.96 (17.20)	139.12 (6.38)	146.57 (14.75)	136.21 (13.10)	150.75 (7.17)	153.02 (17.94)
Weight (mean (SD))	44.98 (16.87)	36.40 (13.07)	51.10 (11.98)	45.37 (15.67)	44.07 (15.57)	33.15 (5.87)	42.52 (14.20)	32.76 (9.98)	43.50 (9.86)	53.06 (22.32)
Body Mass Index (mean (SD))	19.64 (4.46)	18.64 (3.47)	20.32 (3.77)	18.88 (3.23)	18.41 (3.05)	17.05 (2.25)	19.25 (3.51)	17.25 (2.77)	19.00 (3.33)	21.74 (5.96)
Mothers Education (Beyond Compulsory) (%)	8926 (58.6)	1088 (46.5)	103 (22.6)	1165 (79.2)	418 (70.7)	190 (53.4)	30 (4.7)	306 (79.7)	3674 (77.0)	1952 (46.1)
Fathers Education (Beyond Compulsory) (%)	7607 (62.6)	1224 (61.5)	0 (NaN)	1110 (79.3)	354 (65.6)	189 (63.2)	10 (1.7)	323 (86.8)	3074 (73.0)	1323 (47.9)

Note: a = Data not collected in marked study. B = The response categories for mother and father education in EYHS Portugal did not include options for vocational training or distinguish those who started university / further education but did not complete it. It was, therefore, only possible to assign participants to two of the three categories for this harmonised variable (Up to and including completion of compulsory education (coded 0) / Completed undergraduate or postgraduate education (1))

4.3.2 Counts Per Minute.

Using a measure of overall activity, the distribution of activity varied between studies. Compared to the UK, Australians, Swiss, Norwegians and Estonians all observed higher mean counts per minute, while the US, Portuguese and Danish sample all recorded lower counts per minute (Figure 4-2). Despite the differences in overall activity, the UK sample had the lowest observed standard deviation (SD: 186 cpm). In addition to having high average counts per minute, Norway (SD: 282 cpm) and Estonia (SD: 248 cpm) were amongst the most dispersed for counts per minute. However, increased average counts and increased standard deviations did not seem to co-occur. Apart from Norway, almost all nations observed moderate to strong positive skews (Table 4-2), with the single strongest positive skew after adjustment observed for the Australian sample. As with the standard deviation, the most skewed samples were not the most or least active, with the UK and US samples being the second and third most skewed samples respectively.



Country	n	Mean	sd	Median	Skew
AUS	2310	713.95	212.78	688.30	0.68
DEN	1448	538.59	245.54	517.59	0.62
EST	584	625.57	247.77	604.65	0.67
NOR	355	707.29	282.30	694.06	-0.21
POR	617	585.51	233.12	562.19	0.59
SWI	116	743.86	208.95	717.67	0.27
UK	4761	587.90	185.87	556.45	0.89
USA	3949	515.27	221.01	479.07	0.93

Figure 4-2: Density plot of mean counts per minute by country, plot is censored at 1,500 cpm to centre of distribution. Exclusion criteria are as outlined in section 3.2.4

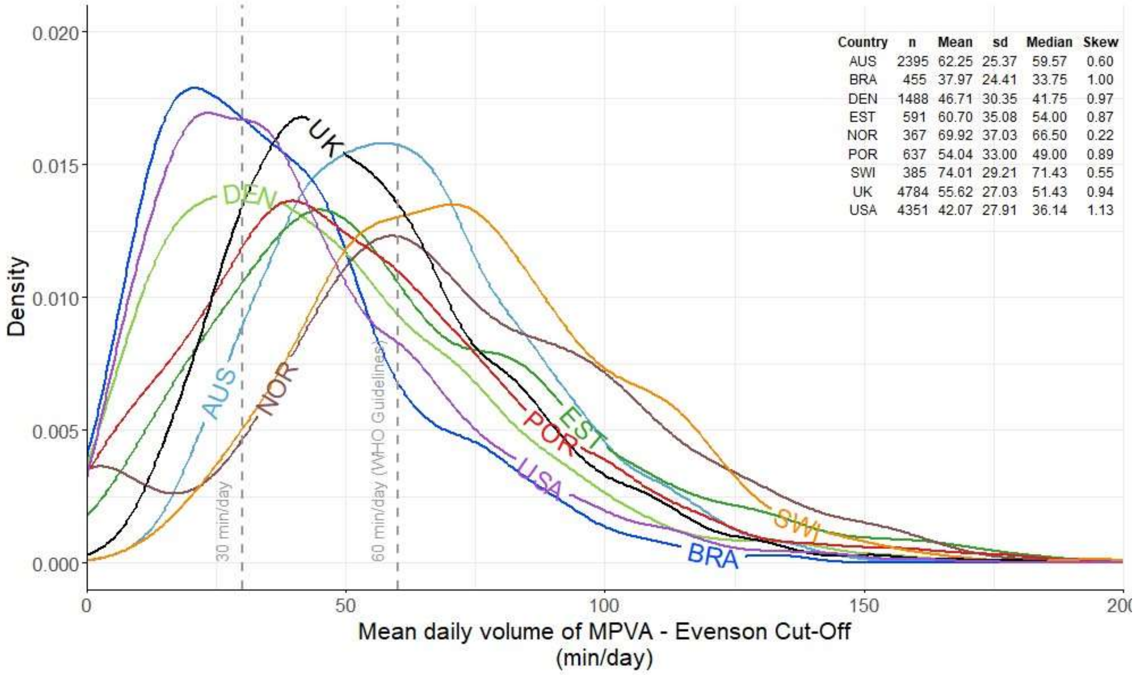
Table 4-2: Adjusted association between country of study and physical activity as measured by counts per minute.

Country	N (%)	NO distribution		BCCG distribution	
		Mean % Difference (SE)	SD % Difference (SE)	Median % Difference (SE)	Skewness[b]
United Kingdom (ref)	4761 (34.46)	546.35	175.57	530.55	0.36
Australia	2287 (16.55)	19.49 (0.76) ***	14.93 (1.8) ***	19.33 (0.76) ***	-0.16 (0.07) ***
Denmark	1148 (8.31)	-8.83 (1.25) ***	31.69 (2.12) ***	-9.69 (1.2) ***	0.27 (0.06)
Estonia	584 (4.23)	5.85 (1.62) ***	29.89 (3.1) ***	4.78 (1.6) **	0.16 (0.09) ***
Norway	355 (2.57)	16.24 (2.13) ***	45.64 (3.89) ***	18.99 (1.76) ***	1.04 (0.1)
Portugal	617 (4.47)	-3.27 (1.66) *	22.51 (3.03) ***	-2.41 (1.57)	0.46 (0.09)
Switzerland	116 (0.84)	20.87 (2.48) ***	11.32 (6.64)	22.48 (2.47) ***	0.27 (0.26) ***
USA	3949 (28.58)	-13.03 (0.82) ***	18.47 (1.52) ***	-15.92 (0.81) ***	0.01 (0.05) ***

Note: Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean). NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE

4.3.3 Moderate to Vigorous Physical Activity (MVPA).

The distribution of MVPA differed between the contributing studies. Mean volumes of MVPA varied notably between studies, from 38 min/day in Brazil to 72 min/day in Switzerland. Four studies reported both a mean volume of activity above the 60 min/day threshold and a positive differential with the UK. In order these were Estonia (Mean: 61 min/day, +8%), Australia (Mean: 62 min/day, +11%), Norway (Mean: 69 min/day, +19%), and Switzerland: (Mean: 72 min/day, +27%) (Figure 4-3 & Table 4-3). While the UK had a comparatively low standard deviation, a more active study (Australia: Mean = 62 min/day) and a less active study (Brazil: Mean= 38 min/day) both observed less variation. Mirroring observations in cpm, two of the more active studies on average were the most variable (Norway and Estonia), however a higher average volume of MVPA did not appear to consistently occur with a higher standard deviation. All of the samples were moderately to strongly skewed, with an exception of the Norwegian sample, which despite the greater variation more closely approximated a normal distribution (Figure 4-3 & Table 4-3).



Country	n	Mean	sd	Median	Skew
AUS	2395	62.25	25.37	59.57	0.60
BRA	455	37.97	24.41	33.75	1.00
DEN	1488	46.71	30.35	41.75	0.97
EST	591	60.70	35.08	54.00	0.87
NOR	367	69.92	37.03	66.50	0.22
POR	637	54.04	33.00	49.00	0.89
SWI	385	74.01	29.21	71.43	0.55
UK	4784	55.62	27.03	51.43	0.94
USA	4351	42.07	27.91	36.14	1.13

Figure 4-3: Density plot of moderate to vigorous activity as defined by Evenson cut points. Each line representing a different country in the study. Plot is censored at 200 min/day to show centre of distribution. 60 minutes per day and 30 minutes per day are marked by vertical dashed lines.

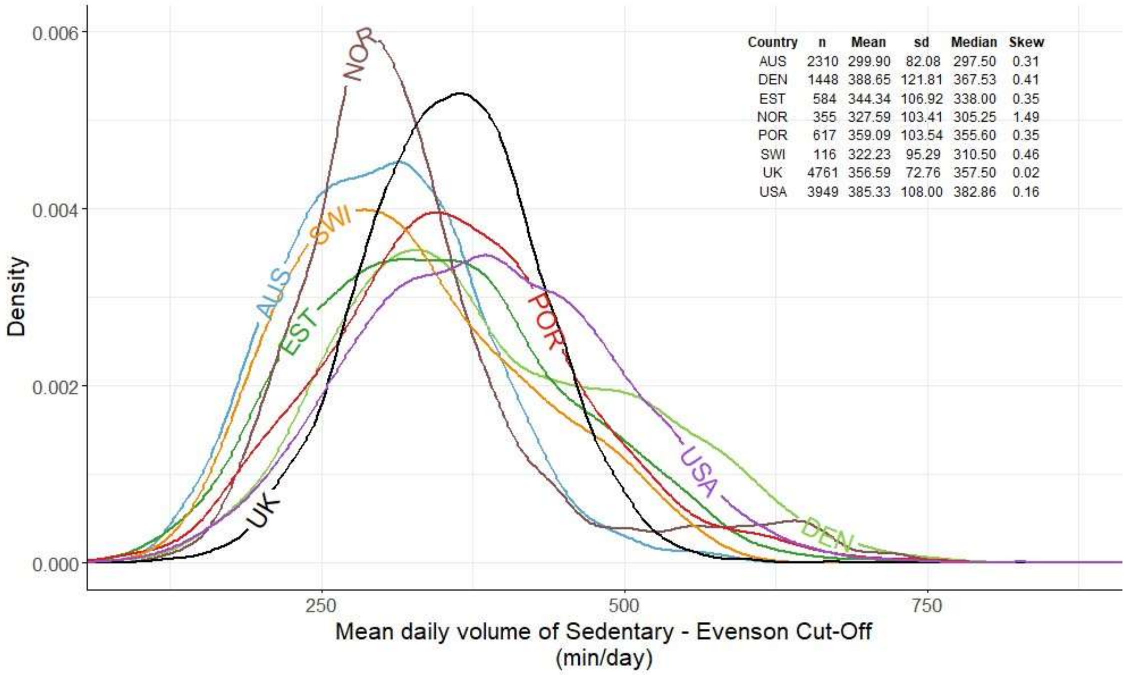
Table 4-3: Adjusted association between country of study and moderate to vigorous activity defined by Evenson cut points, measured as minutes per day.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^{b}**
United Kingdom (ref)	4785 (43.19)	47.1	24.79	45.09	0.49
Australia	2372 (21.41)	11.3 (1.02)	-6.69 (1.78) ***	13.73 (1.02) ***	0.03 (0.05) ***
Brazil	455 (4.11)	-43.72 (3.02) ***	-4.76 (3.47)	-49.7 (3.06) ***	-0.06 (0.06) ***
Denmark	1488 (13.43)	-17.68 (1.73) ***	16.75 (2.1) ***	-22.22 (1.69) ***	0.06 (0.04) ***
Estonia	591 (5.33)	7.71 (2.34)	30.3 (3.08) ***	6.04 (2.3) **	0.07 (0.06) ***
Norway	367 (3.31)	18.73 (2.71)	35.99 (3.83) ***	19.51 (2.63) ***	0.3 (0.07)
Portugal	637 (5.75)	-6.62 (2.39) ***	20.9 (2.98) ***	-10.91 (2.37) ***	0.17 (0.05)
Switzerland	385 (2.49)	27.29 (1.88)	4.55 (3.75)	30.19 (1.89) ***	0.08 (0.11) ***
USA	4351 (28.2)	-26.97 (1.15) ***	3.89 (1.48) **	-35.43 (1.16) ***	-0.03 (0.03) ***

Note: Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean). NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$. Values are reported as % and SE

4.3.4 *Sedentary activity.*

Volumes of inactivity were lowest in Australia (Mean = 300 min/day, -16%) and greatest in Denmark (Mean = 388 min/day, +9%) but all nations observed a mean volume of sedentary behaviour falling between 300 and 400 minutes per day. The UK sample was relatively normally distributed (Table 4-4 & Figure 4-4) with almost all other studies observing low positive skews. The exception was the Norwegian sample, which was highly positively skewed, which may be caused by the cluster of individuals spending approximately 10hrs a day sedentary (brown line in Figure 4-4). In addition to the lowest skew, the British sample had the lowest deviation (SD: 73 min/day), with the largest increase on this observed for the Danish Sample (SD = 122 min/day, +52%), which may be resultant from the weakly multimodal distribution (light green line in Figure 4-4). Overall, there appears to be a loose trend of higher mean volumes of sedentary behaviour occurring alongside greater standard deviations amongst the included studies.



Country	n	Mean	sd	Median	Skew
AUS	2310	299.90	82.08	297.50	0.31
DEN	1448	388.65	121.81	367.53	0.41
EST	584	344.34	106.92	338.00	0.35
NOR	355	327.59	103.41	305.25	1.49
POR	617	359.09	103.54	355.60	0.35
SWI	116	322.23	95.29	310.50	0.46
UK	4761	356.59	72.76	357.50	0.02
USA	3949	385.33	108.00	382.86	0.16

Figure 4-4: Density plot of mean daily volume of sedentary activity as defined by Evenson cut points, presented by country. Exclusion criteria are as outlined in section 3.2.4

Table 4-4: Adjusted association between country of study and sedentary activity defined by Evenson cut points, measured as minutes per day.

Country	N (%)	NO distribution		BCCG distribution	
		Mean % Difference (SE)	SD % Difference (SE)	Median % Difference (SE)	Skewness^b
United Kingdom (ref)	4761 (34.46)	354.18	72.09	353.73	0.97
Australia	2287 (16.55)	-16.7 (0.66) ***	12.4 (1.8) ***	-18.22 (0.65) ***	-0.38 (0.08) ***
Denmark	1148 (8.31)	8.57 (0.87) ***	52.21 (2.12) ***	5.67 (0.87) ***	-0.57 (0.08) ***
Estonia	584 (4.23)	-3.09 (1.3) *	38.13 (3.1) ***	-5.44 (1.3) ***	-0.44 (0.11) ***
Norway	355 (2.57)	-7.38 (1.69) ***	35.11 (3.89) ***	-13.62 (1.46) ***	-1.49 (0.16) ***
Portugal	617 (4.47)	3.77 (1.26) **	34.79 (3.03) ***	2.24 (1.23)	-0.3 (0.12) ***
Switzerland	116 (0.84)	-9.72 (2.76) ***	27.95 (6.64) ***	-13.21 (2.78) ***	-0.81 (0.24) ***
USA	3949 (28.58)	8.66 (0.56) ***	39.91 (1.52) ***	7.83 (0.55) ***	-0.19 (0.07) ***

Note: Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean). NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE

4.3.5 Light activity.

Most nations clustered around 6hrs/day of light activity with the UK sample having a mean of 364min/day of light activity. The studies with the highest volumes of light intensity activity broadly mirrored observations for MVPA, being highest amongst the Australians, Swiss, Norwegians and Estonian samples. Unlike observations for MVPA, most studies were closer to a normal distribution with most studies returning low, negative skews. Exceptions to this were the Portuguese and Norwegian samples which respectively observed a moderate and strong negative skew (Table 4-5). The two studies with the lowest mean volumes of light intensity activity also observed the greatest standard deviations (USA: Mean = 348 min/day, SD = 88min/day; Denmark: Mean = 353 min/day, SD = 96min/day). Low averages and high deviations did not appear to be a consistent trend, as the studies with the second and third highest volumes of light intensity activity had the third and fourth highest standard deviations (Estonia and Norway). Again, mirroring observations for cpm and MVPA, the UK, Australian and Swiss samples were the least dispersed.

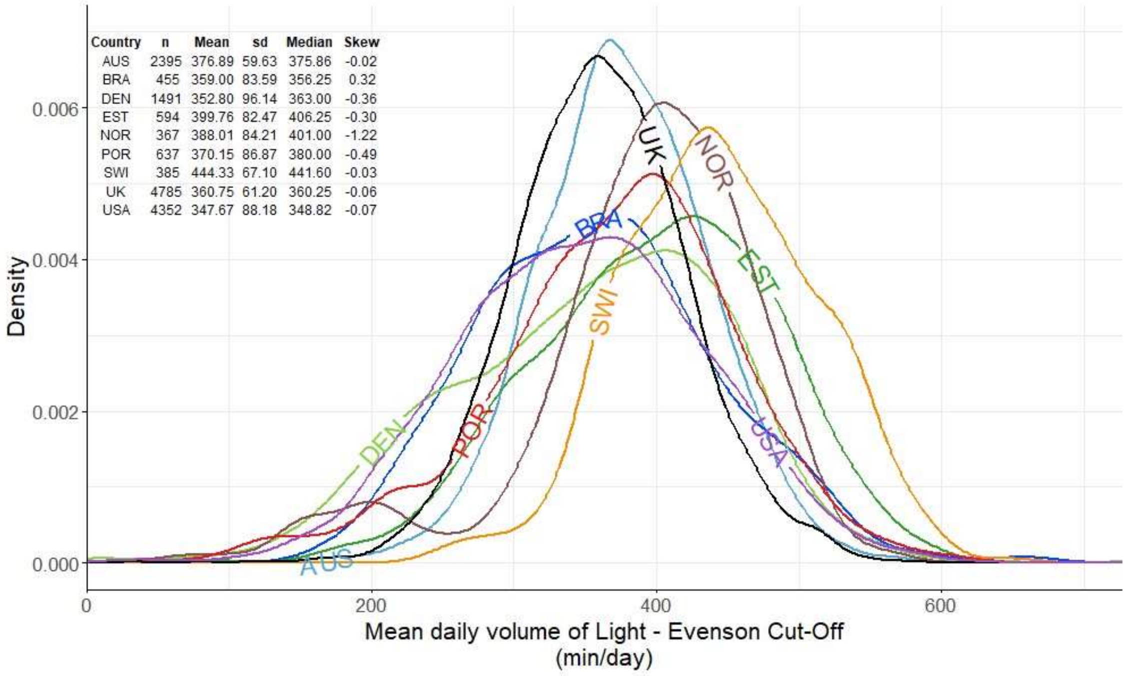

Country	n	Mean	sd	Median	Skew
AUS	2395	376.89	59.63	375.86	-0.02
BRA	455	359.00	83.59	356.25	0.32
DEN	1491	352.80	96.14	363.00	-0.36
EST	594	399.76	82.47	406.25	-0.30
NOR	367	388.01	84.21	401.00	-1.22
POR	637	370.15	86.87	380.00	-0.49
SWI	385	444.33	67.10	441.60	-0.03
UK	4785	360.75	61.20	360.25	-0.06
USA	4352	347.67	88.18	348.82	-0.07

Figure 4-5: Density plot of mean daily volume of light activity as defined by Evenson cut points, presented by country. Exclusion criteria are as outlined in section 3.2.4

Table 4-5: Adjusted association between country of study and light activity defined by Evenson cut points, measured as minutes per day.

Country	**N (%)**	**NO distribution**		**BCCG distribution**	
		Mean % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
United Kingdom (ref)	4785 (43.16)	364.1	61.14	364.93	1.15
Australia	2372 (21.4)	4.08 (0.42)	-2.18 (1.78)	3.93 (0.41) ***	-0.08 (0.12) ***
Brazil	455 (4.1)	-1.46 (1.14) ***	30.57 (3.47) ***	-3.11 (1.13) **	-0.64 (0.17) ***
Denmark	1491 (13.45)	-2.25 (0.75) ***	45.23 (2.1) ***	-0.97 (0.64)	0.36 (0.1)
Estonia	594 (5.36)	10.08 (0.88)	29.97 (3.08) ***	10.88 (0.8) ***	0.32 (0.17) ***
Norway	367 (3.31)	6.91 (1.16)	31.51 (3.83) ***	9.01 (0.81) ***	1.88 (0.22)
Portugal	637 (5.75)	1.4 (1.01)	35.02 (2.98) ***	2.76 (0.87) **	0.55 (0.15)
Switzerland	385 (2.49)	20.79 (0.81)	9.29 (3.75) *	20.67 (0.79) ***	-0.08 (0.26) ***
USA	4352 (28.19)	-4.08 (0.48) ***	36.48 (1.48) ***	-4.07 (0.45) ***	-0.06 (0.08) ***

Note: Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean). NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE

4.3.6 Sensitivity Analyses

Presented in this section are the adjusted results. The unadjusted results with the same sample returned no meaningful difference in results (see Appendix B.1). Repeating the base model of physical activity being a function of nation of study with the unrestricted dataset, no meaningful difference in result was observed (See Appendix B.2). Adjusted models additionally including season did not observe a change in effect size for nation of study at any intensity (See AppendixB.3). Additionally adjusting for ethnicity only resulted in a notable change in effect from Denmark, but this is likely caused by individuals with missing data for this measure having lower activity than individuals with complete data for ethnicity (See Figure S B-5), no meaningful change was observed for any other intensity (See Appendix B.4). Adjusting for wear time did not lead to any meaningful differences in the model estimates apart from estimates for the Brazilian and Swiss studies in which some participants did not remove the device during sleep (See Table S B-25, Table S B-26, Table S B-27, Table S B-28 & Figure S A-2). No meaningful difference was observed when separating MVPA into moderate and vigorous activity (See Appendix B.6 & B.7)

4.4 Discussion

4.4.1 Summary of results.

The distribution of activity varied across the included studies, the degree of which differed between the different thresholds of activity. Mirroring observations for gender in Chapter 3, the variation in standard deviations increased with increasing intensity of activity. The variance was lower for sedentary and light activity and highest for moderate to vigorous activity.[302,304,305] Mirroring this, the skew degree of skewness was greater at greater intensities of movement. However, unlike gender for which little meaningful difference in distribution was observed for light intensity activities, country of study did appear to have a meaningful influence on the distribution of light intensity activity.

Overall, samples that observed higher variation for one measure were likely to observe higher variation in all measures. Exemplifying this, the UK and Australian samples observed relatively low measures of standard deviation throughout, with the Norwegian and Estonian samples showing relatively high deviations for most intensities. By measures of cpm and MVPA the most active samples on average were not necessarily the most dispersed. While the Norwegian sample observed the largest standard deviation, the Swiss and Australian samples observed notably smaller standard deviations. For volumes of light activity, the samples with the lowest average volumes (Danish and US) had the highest standard deviations, but beyond this no particular pattern between mean and standard deviation was noted. In contrast, for sedentary behaviour there was a loose trend of higher mean volumes occurring alongside greater standard deviations. Here the Danish and US samples observed both the highest volume and the highest standard deviations, while those with lower mean volumes typically had low deviations.

4.4.2 Difference in distribution between intensities of activity

Counts per minute, an approximate measure of total physical activity, are not subjected to any thresholds. By this measure the most active samples in order are the Swiss, Australians and Norwegians. While these three samples also recorded the highest mean volumes of MVPA, they also observed high volumes of light activity and low levels of sedentary activity, indicating that it is activity across the whole spectrum of intensities rather than just the most active thresholds that underly total volumes of activity. As such, when comparing groups, relying solely on measures of MVPA may overvalue the contribution of more intensive activities like sport and active play, and minimise the influence of light intensity activites.[302,304,305] Apart from Norway (discussed below), both the Swiss and Australian samples had low standard deviations, implying that there is greater equality in activity between individuals, with fewer individuals at either extreme of the distribution.

For both mean counts per minute and volumes of MVPA, most samples observed a positive skew in their distribution. As such, for most samples there are a minority of individuals who have undertaken a higher volume of activity, resulting in a non-normal distribution. For MVPA, the largest skews were observed for the samples with the lowest mean volumes (US, Brazilian, Danish). This may be taken to mean that amongst these samples there is greater inequality in access to and uptake of leisure-time activity (like sports and active play),[302,304,305] resulting in a skewed sample where a small proportion of individuals undertook these moderate to vigorous activities.

The positive skew observed for MVPA can lead to the mean over representing the physical activity level of most individuals. This can be illustrated using the results from Estonia. While Estonia did not show the most skewed distribution of MVPA, the mean volume in this sample is roughly equivalent to WHO guidelines of 60min/day (Mean = 60.70 min/day). If individuals were normally distributed 50.79% of the sample should equal or exceed 60 minutes a day of MVPA, yet in this sample only 42.47% (n = 251) manage to do so. This lends some support to using the proportion of individuals who meet or exceed 60min/day of MVPA as the summary metric, rather than the mean volume, when comparing population levels of MVPA.

Compared to MVPA, distributions of light and sedentary activity were less skewed, showing a more even spread between individuals doing more or less than average. The samples were less dispersed for measures of the mean, with the scale of difference with the UK less than 10% in most instances. Individually, the Danish and US sample observed the highest mean volume of sedentary activity, at almost 6hr30 each per day, and the highest standard deviations at approximately 2hr each. This may indicate that in these groups' individuals have greater influence over their volumes of sedentary behaviour, facilitating both a higher mean and standard deviation. Unlike sedentary behaviour, greater volumes of light activity did not occur with higher standard deviations, instead the two samples with lowest mean volumes (US and Danish) observed the highest variability. This could be taken to imply that where a requirement for light activity is more uniform across a population (such as through curriculum design or public infrastructure) rather than light activity being due to volitional uptake, mean volumes are higher.

Compared to country, gender was associated with a smaller effect size for the volume of sedentary (Difference in Mean: 5%; SD: 1%) and light activity (Difference in Mean: 1%; SD: 2%), but a more notable effect size in the distribution of MVPA (Difference in Mean: 38%; SD: 30%). Together this may imply that for the more intensive activities, gendered cultural stereotypes have a larger influence on volumes of activity, with larger differences between the genders underlying some of the variation within the population. However, the Portuguese sample highlights this cannot be the only cultural driver of variance within a population as they had relatively high levels of standard deviation for cpm and volumes of MVPA, yet they were observed to have little difference between the genders in Chapter 3.

Broadly, some results from this chapter here match the observational Global Physical Activity report card, which noted Scandinavian countries to be amongst the most active nations, with central European and affluent Oceanic nations to be middling. Similar to observations in Chaput et al.'s (2018) research, the present study observed greater equality amongst less intensive activities.[348] Equally amongst results for MVPA, not notable association between the mean and the variation were observed for either study.

Unlike their findings, samples with higher average volumes of sedentary activity were less equitable.

4.4.3 *Overall distribution of activity within samples.*

The British participants taken from the ALSPAC dataset were not the most active, being consistently observed to be middling for cpm, and volumes of MVPA and Light intensity activity, but were amongst the most equitable for each measure. The reduced disparity amongst the UK samples means that despite having a lower mean volume of MVPA than the Estonian sample (UK: 56 min/day, Estonia: 61 min/day), a larger proportion of UK sample exceeded 30 minutes per day of MVPA (UK: 84%, Estonia: 82%). The implication is that while there may not be as much opportunity to be active as there is for the Estonian, Swiss, or Norwegian sample, opportunities are more equally distributed amongst the population. While this result could be due to the other samples included being more variable due to small samples sizes restricting representativeness, the US is also more variable than the UK sample despite being almost as large and likely more representative.[260] Instead the UK sample may accurately represent an equitable distribution of activity amongst children in the Avon region, which is likely be more affluent than the broader British population,[362] with the potential for greater variation across the whole UK population.

The sample from the USA recorded the second lowest counts per minute and volume of MVPA, with the most skewed distribution for each of these measures of the included studies (Figure 4-2 & Figure 4-3). In line with previous observations, such a divide in the population, in which most individuals record very little MVPA with a small subset recording a large amount of activity could be driven by unequal, stratified opportunities to access sports and active play. Linked with this is the low level of school based physical education classes, with less than a third of adolescent students having at least one hour of school based sports per week.[359] This likely results in MVPA in the USA being constituent of activities engaged in outside of school settings which will be subject to both social stratification and individual attitudes towards sports and active play.[359,363] This is compounded by access and proximity to green spaces being partially subject to social stratification in the US.[364] With greater greenspace availability associated with increased odds of undertaking MVPA on at least 5 days of the week,[365] this compounds previously highlighted issues by limiting opportunities for active play amongst less affluent individuals.

A reduced access to spaces to be active is combined with a low uptake of active transport to school in the USA. With less than 40% of children reporting any active transport in any setting in a given week.[350] With a separate study observing less than 10% of US students reporting frequent active transport to and from school.[366] With active transport to school increasing the likelihood of meeting health targets,[354,367] such low uptake in the US could exacerbate the divide between individuals who are doing the median amount of activity from those at the upper tail.

The Norwegian sample observed a different distribution to most other nations in the volume of MVPA and the mean counts per minute. Notably, this distribution was bimodal with a large group clustered around the mean, but with a small group clustered at very low volumes of MVPA (Figure 4-3) and mean counts per minute (Figure 4-2). The slight oversampling of highly inactive individuals in this sample could partially be caused by the season of recording (Figure S B-1). Of the included the samples, the Norwegian comes from the highest latitude, with the shortest length of winter day light hours (minimum of 5hr54), meaning there is less time to be active outdoors. This, when combined with a small sample size (in comparison to the other nations included, see Table 4-1), may overrepresent these individuals in the sample compared to the population level distribution. However, the Estonian sample, has a similarly short winter day length (6hr20) and climate, yet does not have similarly skewed distributions.

Brazilians in this sample recorded the lowest volume of MVPA which did not match observations based on self-report data in the Physical Activity Global Report Card.[104] This ranks both the USA and Estonia lower than Brazil for overall activity score in children and youth. However, in the UNESCO report on school based physical activity, Brazil ranked lowest of the countries included in this study.[368] Brazil also observed the lowest standard deviation and second strongest positive skew with a small proportion of individuals with activity levels above recommended levels (17% recorded ≥ 60min/day), and many individuals with low activity (45% recorded ≤ 30min/day).

The accelerometer sweep in the Pelotas study included those who had provided information at each of the previous sweeps in the study, which may result in the accelerometer sample being more affluent than the population its representing, as previous studies have observed missing not at random to under represent those of lower socioeconomic standing.[369,370] In the other constituent nations, increasing affluence may increase access to sports and leisure.[322,323,363,371,372] In the Pelotas study, increasing affluence may instead facilitate a reduction in activity if active behaviours can be replaced, such as replacing walking to school with motor transport.[321] Similar observations have been seen in subsequent accelerometer sweeps of the Pelotas study,[285] and in subsistence populations when transitioning to market integration.[373] This is combined with a small analytical sample after restriction to complete cases (n = 455) which may bias the sample to represent a under representative, underactive selection of Brazilian society.

4.4.4 The distribution of physical activity and its association with health.

If the studies accurately account for the latent distribution of physical activity within the populations, the implication would be that less active populations on average have a greater likelihood of experiencing poorer activity related health, but furthermore that those with greater variation should have less equality in activity related health. Compared to the UNICEF Innocenti 2020 Report Card of children’s health and wellbeing, populations with better physical health amongst children loosely appeared to be more active within the present study.[374]

Table 4-6: Relative ranks of nations based on Counts per minute as presented in Table 4-2 and the UNICEF Innocenti Report 2020 ranking of physical health amongst children from rich countries.[374]

Country of Study	*Physical Activity As measured by CPM Rank (of 8)*	*UNICEF Innocenti Report Physical Health Rank (of 38)*
Switzerland	1	3
Australia	2	28
Norway	3	8
Estonia	4	15
United Kingdom	5	19
Portugal	6	26
Denmark	7	4
United States of America	8	38

Note: Gradings for physical health within the Innocenti Report are based on rates of child mortality between ages 5 and 14, and percentage of children aged 5-19 classed as 'overweight'. Additionally, the UNICEF report does not include Brazil.

Though there are many other factors beyond physical activity that influence overall health,[375] rankings loosely correlate between the present results and the UNICEF report for child physical health. Lacking in the UNICEF report is a measure of health inequality amongst children. Taking the US NHANES sample, which had one of the lowest counts per minute and the highest volumes of sedentary behaviour on average as well as being amongst the greatest standard deviations for both. All else being equal, the expectation would be that these children would experience poorer activity related health (as observed in Table 4-6), but additionally be the most unequal in the distribution of health outcomes. While the US does have a high degree of health inequality, it is likely that broader socio-economic factors underlie both the inequality in health and in physical activity.[376,377] Whereas, the UK may have middling values for both physical activity and physical health, it may be more equally distributed amongst the population (Table 4-6).

Two notable exceptions are visible, that of Australia and Denmark, with their relative positioning flipped between the two measures. Limitations with waist-worn uniaxial accelerometery may partially explain the difference between Danish physical activity in the present study and their relative physical health in the UNICEF report. Namely, accelerometers are poor at accounting for cycling.[273] Amongst Danish youth, approximately 80% of children report cycling to school at least twice per week,[350] with the Global Physical activity report card only scoring Dutch children as more likely to use active transport.[104] This daily activity would be largely unaccounted for within the present study.

For the disparity in the Australian rankings, in the present study, there a few potential contributing factors. Of the included studies, the Australian sample was one of the youngest (Table 4-1), which given the negative association between age and physical activity in the ICAD sample (Figure S A-3), may give an elevated impression of overall childhood activity. With the children all came from Melbourne the sample may not have been representative of broader trends in Australian physical activity, as it may also have drawn from more affluent families than the rest of Australia.[378]

4.4.5 Strengths

In a large multinational sample of children's accelerometry data, both this study and Chapter 3 have leant support for the need to explore physical activity as a broad concept, incorporating the full distribution of physical activity across the intensity spectrum. This study observed similar differences between nations in their volumes of physical activity to previous research,[7,8,294] but expands upon this to highlight differences in the full distribution of activity that have not previously been explored within the childhood physical activity literature. In particular how the entire distribution can be used to highlight inequality in activity missed by studies of averages.

While this is not the first study to examine cross-national differences in the distribution of activity amongst youth, this research expands on previous work by Chaput et al., (2018) in which they focus on the role of MVPA and sedentary behaviour in determining obesity rate. It does so by using a GAMLSS approach to incorporate non-normally distributed data to examine multiple dimensions of the distribution, including measures of central tendency, variation, and skewness. In doing so, this research highlights the broader value that a GAMLSS approach can offer in the research of an exposure or behaviour that is either asymmetrically distributed or is observed to have a non-linear relationship with an outcome, such as health.

4.4.6 Limitations

The three most active nations as defined by counts per minute, were also the three youngest samples on average. With their relative ranking mirrored with the Swiss sample being the youngest (Mean age: 9.31 years), followed by Australia (Mean: 9.62 years), and Norway (Mean: 9.68). While the inverse association of age and physical activity observed here (Figure S A-3) and elsewhere[379,380] could partially be underlying this observation, the effect size was robust to the inclusion of age. To caveat these results, of these, two (Switzerland and Norway) were the smallest sample sizes. As such, these results may not be the most representative of the broader populations and may be more prone to overrepresenting more active members within the broader population.

Some limitations to the ICAD dataset have previously been discussed in section 2.1.2 and 3.4.4, but with relevance to cross-national differences, this research is limited by the cultural variation in included nations.[247] Future research could be built upon by including a broader array of nations. With trajectories of physical activity inflected by the transition to formal schooling[7,8,379] longitudinal data during these periods combined with a GAMLSS approach could help develop an understanding of what occurs during these periods. Here and in Chapter 3, each included study is used to represent the broader activity patterns of the national population. However, their ability to accurately do so varies. As discussed above, the NHANES and ALSPAC are the two largest samples included here but differ in their degree of representation of the broader population. While NHANES is designed to broadly representative of the US,[260] ALSPAC is representative children in the Bristol and Avon area, which are likely to be more affluent than the wider British population.[314] Further compromising the ability to be representative is the variable sample sizes amongst the included studies, which may leave smaller samples open to misrepresenting the relative contribution of differing subsets of the population, as discussed above for the Norwegian sample. Finally, though broadly similar in their study designs, there is some variance in how the studies are conducted. For instance, participants in both the Swiss KISS study and Brazilian Pelotas study observed longer wear times, notably by not removing the device at night. As seen in the sensitivity analyses this would lead to an overreporting of sedentary time (with sleep being classed as sedentary), which in turn when adjusting for wear time would lead to other intensities forming a smaller fraction of the day. Despite these issues, at present, ICAD remains the best, freely available resource to compare objective patterns of activity between nations.

While the present studies focus on cross-national differences, other demographic variables warrant study. As an example, it may be that within a nation, there may be more variability amongst individuals of higher affluence who may be able to afford to choose whether to partake in extra-curricular sport or not. As observed in the low degree of variation amongst the ALPSAC dataset, it may be that markers of regional affluence (such as access public and leisure facilities that may be unevenly distributed across a population) have an impact on activity that could not be evaluated here.

4.4.7 Conclusions and links to other chapters.

Overall, the implication is that populations that are more active by average measures of MVPA are no more likely to have an equitable distribution of these activities than less active populaces. Instead, where light activity is facilitated, or sedentary behaviour tackled, there appears to be a more even and equitable distribution of the effect across the population. While the relative ranking of samples by counts per minute were similar with those for volumes of MVPA, they also mirror rankings for volumes of often overlooked light intensity activity. As such, increasing the volumes of MVPA may bring about increases in the average amount of activity, but there is no guarantee that this would be equitable across the population, whereas increasing the amount of light activity may also increase the average amount of overall activity, but may do so in a more equitable manner.

Expanding on differences between genders in Chapter 3, this chapter employed a similar methodology to reveal notable differences between studies from affluent nations. Expanding on cross-cultural comparisons of physical activity patterns to include non-industrial populations, a study comparing BaYaka hunter-gatherer children and British children in the MCS study and American children in the 2013 NHANES dataset is conducted in Chapter 6. An introduction to the role of ecology in forming population specific physical activity patterns is discussed in section 1.2 with a wider discussion on the role of physical activity is included in section 1.1. The limitations introduced here centre on this study, for a broader discussion of the relative strengths and weaknesses employing accelerometery to measure physical activity is included in section 2.1.

Chapter 5 Physical activity in the BaYaka hunter-gatherers

Main Objective: To quantify patterns of physical activity in BaYaka Hunter-Gatherers using an objective measure of activity and to examine differences by gender, maternal status, market integration and age.

Background: Research into the physical activity of hunter-gatherers has been limited to a small number of studies, with small samples and a variety of methodologies. Using data from an understudied population of hunter-gatherers, this chapter aims to add detail to how physical activity differs across a subsistence population, in regard to gender, reproductive status, market integration and age.

Methods: To test the association between physical activity and gender, age, maternal status (pregnant/lactating or non) and proximity to town, accelerometry data was collected from a sample 126 (Men = 55) BaYaka hunter-gatherers from Congo-Brazzaville. These demographics were examined in relation to overall volumes of activity (mean acceleration) as well as different categories of activity intensity (Sedentary, light, and moderate to vigorous activity).

Results: BaYaka adults (Approx ages 16-50, N=88) undertook more moderate to vigorous physical activity (MVPA) in a day than the WHO recommends in a week (199 mins/day vs 150mins/week). Men did observe slightly higher mean accelerations, driven by a greater amount of time in vigorous intensity activities. Overall levels of activity were greatest amongst young adults and lowest amongst older adults. Amongst reproductively aged women, no difference according to maternal status was observed. Additionally, no variation in activity with market proximity was observed for either gender. Patterns of activity differed between age groups, .

Conclusions: Unlike sedentary post-industrial populations, amongst the highly active BaYaka, activity was greatest in early adulthood, mirroring proposed peaks in foraging productivity. While men undertook more activity than women, no support for reproductive factors underlying this difference was observed amongst the BaYaka. Despite previous observations of behaviours changing in response to market integration amongst this population, no association between market proximity and physical activity was observed.

5.1 Introduction

5.1.1 Studying hunter-gatherers to expand on a post-industrial perspective of health.

People living in post-industrial nations experience a very different style of life from the hunting and gathering that characterises most of human evolutionary history.[25] Notably over the last century, subsistence in post-industrial nations has transitioned away from manual work with livelihoods supportable from a sedentary form of labour.[23,94,381] As outlined in section 1.2.3, in trying to understand the health impacts of physical (in)activity it can therefore be useful to understand what patterns of activity were like in the hunting and gathering niche that humans evolved in.

While some previous studies of hunter-gatherer populations have tried to do exactly that,[87,126,131,157] a defining feature of humans is the ability to adapt behaviour through culture to an array of ecologies. To understand hunter-gatherer physical activity, taking a value from one population, in one ecology, will not reflect the breadth of potential behavioural responses. As such, there is value to studying other populations engaging in a similar subsistence style of hunting and gathering in different environments, to better understand the behaviours that are consistent between populations and the factors that lead to differences. The lack of ecological breadth to date, combined with the small sample sizes limits the external generalisability of the findings to other populations, including comparisons to post-industrial nations.

For populations with constrained access to energy, where obtaining additional calories costs additional calories, energy conservation is of the utmost importance. Chronic undernourishment or a state of low energy availability can incur a large fitness cost through stunted growth, delayed maturation, greater susceptibility to illness and shorter overall lifespan.[382,383] As such, behaviours that help avoid such calorie shortfalls should be favoured. While ecological factors may require higher levels of physical activity in hunter-gatherers, in respect to energy conservation, being as inactive, or sedentary, as possible is the ideal state of being from an evolutionary perspective.[24,131] As such, the health benefits associated with a hunter-gatherer lifestyle should be seen as a compromise between being active enough to acquire calories, but not to consume more calories than is necessary.

For hunter-gatherers, saving energy whenever possible should be a highly conserved trait to help individuals survive periods of low calorie availability. Until the recent extreme manifestation of calorie conservation seen in the obesity epidemic,[384] the benefits of excess available energy pay-out, through reproduction, before the costs of increased mortality and morbidity increase at older ages.[385,386] While adiposity has a curvilinear relationship with fertility, with low fertility associated with both low[387] and high adiposity[388] in both men and women, rarely is overweight or obesity observed in extant hunter-gatherer populations.[79,87,127] Since the reproductive costs of excess adiposity are rarely encountered in hunter-gatherer populations but the costs of low adiposity more frequently are, any underlying mechanisms to conserve calories are unlikely to be selected against amongst these subsistence populations.

If reducing energy output is a key factor in determining physical activity profiles, it should be expected to manifest through a reduction in the intensity of activities wherever possible. Individuals should operate at the lowest intensity possible for the activities they are engaged in and only undertake as much activity as is necessary. As such, where remaining sedentary is not possible, hunter-gatherers should preferentially operate in light activity thresholds, followed by moderate and finally vigorous intensities. Only doing as much activity as is required to maximise their fitness in a foraging niche, including obtain enough calories, maintain social bonds and raising children. Without even factoring in the relaxed access to calories post-industrial life offers, an evolved drive to reduce activity where possible, mismatched into an ecology that can sustain lives at low levels of activity radically shifts the balance of energy in post-industrial populations.

However, hunter-gatherers need to be active to maximise their fitness (including amongst other activities, obtaining enough food and water, maintaining social bonds, caring for children). As such, hunter-gatherer physical activity should embody the trade-off between requiring activity but maximising sedentary behaviour. While sports persons can be used as models of highly active individuals,[172] their trade-offs differ from subsistence populations. For an evolutionary model, fitness is measured in reproductive success, but for athletes it is typically sporting performance. These are two different concepts and maximising one does not necessarily maximise the other. In pursuit of the upper limits of performance, athletes toe the line of how much activity can be done, hunter-gatherers instead should carry out as much activity as needs to be done. Undertaking large volumes of activity has driven the curvilinear relationship between health and activity (Figure 1-1), where beyond an undefined point additional activity no longer benefits health.[69] Athletes can encounter the risks of over training and over expenditure as manifest in Relative Energy Deficiency in Sport (RED-S),[66,69] and the increased risk of acute cardiovascular events during activity.[389] For hunter-gatherers, for whom survival is dependent on an active lifestyle, prolonged injury or compromised health status could impact their reproductive fitness. Hunter-gatherers should therefore be as active as they can be without risking their health over the short or long term. Further, athletes in post-industrial populations are less likely to be constrained in their access to calories, allowing them to consume additional energy to compensate for any over expense.

5.1.2 Using life history theory to predict physical activity across the life course.

Adding further nuance, for all individuals there is a trade-off in energy allocation, among growth, reproduction, maintenance and movement[79]. As discussed in section 1.2.2, the conflicts in energy allocations between these vary across the life course.[142,143] Due to the health risks associated with over spending energy, a drive to maintain energy balance should be relatively conserved.[66,86] At different points of life, the need for investment in reproduction, growth and maintenance vary. One major consciously modifiable output of energy is physical activity as it accounts for up to a third of all energy expenditure.[137] On the premise of physical activity being supressed when other energetic costs rise, predictions of physical activity across the life course from an evolutionary standpoint can be proposed. From a simplified interpretation of constrained energy budgets, when basal metabolic rates are higher, the energy available for movement should be lower.[86,146]

Proportional to size, basal metabolic rates are high in childhood, reflecting the relative costs of growth and development.[146] As these start high and decrease with maturity, physical activity should increase throughout childhood. As girls more often exit puberty before boys,[159] their peak in physical activity may come before boys. Trade-offs should be lower in young adulthood when growth has finished but the costs of reproduction are yet to fully materialise. The energy available from reproductive adults should be similar to young adults, unless they are simultaneously bearing the energetic costs of gestation and lactation.[151] If individuals are ill, more energy may be required for an immune response, which may underlie the proposed sickness response of becoming less mobile when ill.[390] This may partially underlie a potential decrease in activity with age, if more energy is needed to maintain the soma, or if there is an age related decline in mobility.[391,392]

5.1.3 Physical Activity in Hunter-Gatherers.

Explicit quantifications of physical activity within hunter-gatherers have been ongoing for at least the past 20 years (Table S C-1). With time and technology, the strengths of these accounts have improved, moving from ethnographic accounts through measures of energy expenditure, to measures of moderate to vigorous physical activity (MVPA) and accounts of how hunter-gatherers rest. Compared to reference values for an active lifestyle,[76] 14 of 23 studies identified indicate that hunter-gatherers regularly surpass the WHO guidelines for minimum volumes of adult physical activity.[126,393,394] One study of the Hadza of Tanzania (n=46) observed daily amounts of MVPA to be in excess of weekly observations for US adults (135mins/day vs. 64mins/week).[130] Though research emphasis has been dedicated to the higher intensities of physical activity, objective studies on sedentary behaviours in hunter gatherers reveal patterns comparable to developed countries.[131]

Studies typically focus on one behaviour type at a time, whether that be sleep, sedentary behaviour or MVPA, but what is missing in this area of research is a cohesive, singular account of all intensities of physical activity across a day using a measure of generalised physical activity. As time is finite, if an individual engages in more of one physical activity intensity this must be offset with a reduction in another (Increased volumes of MVPA must come at the expense of either sedentary behaviour, light intensity activity, or sleep).[230] As such, benefits found for increasing the amount of MVPA may be explained by the benefits of reducing sedentary behaviours, and vice-versa.[231] Though this method of exploring time allocation is gaining traction with epidemiology it remains a relatively neglected means of examining physical activity, particularly amongst subsistence populations.[230,231,395]

Most research into hunter-gatherer physical activity has been dominated by the Hadza of Tanzania, of whom 9 of the 23 studies identified focussed. While this helps build a deeper understanding of these populations, the research only portrays hunter-gatherer physical activity from a narrow band of ecologies. To build depth in the understanding of hunter-gatherer physical activity, populations with differing ecologies need to be studied. Living in the rainforests, the ecology of the BaYaka will have different constraints on physical activity. Dense forest could restrict movement in a way that open savannah of the Hadza does not. Dense vegetation may constrain the ability to cover distance as efficiently, reducing the daily distances covered. Dense vegetation may also increase upper body activity due to the need to clear paths through the forest. Further, differing diets, and the methods used for of obtaining food may alter activity profiles, as will the cultural practices associated with each population's respective ecology. Subsequently, through the similarities, a general pattern of physical activity associated with a hunter-gatherer mode of subsistence can be stated with more confidence, and from the differences the underlying ecological factors can be explored.

5.1.3.1 Gender differences in physical activity patterns.

As discussed in section 1.1.3.3, amongst post-industrial populations men are often more active than women. While similar results are sometimes seen in studies of hunter-gatherers the results are less consistent. In the literature reviewed pertaining to hunter gatherer activity (see Table S C-1), all 23 studies included sex or gender as a possible factor determining physical activity levels. Of those that used an objective measure amongst predominantly hunting and gathering populations, 4 found a significant difference in the daily physical activity between men and women (Where a study reported both physical activity inferred from movement, and by energy expenditure, only movement is discussed here), 1 of which observed women to have higher physical activity (Figure 5-1).[126] However, of these studies, over half were conducted with the Hadza of Tanzania. Notably, when measuring daily distances, Hadza men are estimated to cover significantly more ground each day than women in both adulthood (11.4km vs 5.8km)[79] and childhood (9.4km vs. 8.0km at age 10).[396]

In two other studies by the same research group, when a measure of whole-body activity was used instead, a difference in activity between the men and women was not found.[130,224] In this population, men's activity may be characterised by lower body movements such as walking meaning that measures of the lower body or distances covered may bias results towards men. Whereas women's activity relies more upper body movements such as digging for tubers,[79] which may reduce the disparity when a whole body measure is used. At the other end of the activity spectrum, no sex or gender difference was found in the amount of inactivity[131] or time spent asleep,[397] including time in bed, sleep duration, and sleep efficiency. This body of research supports a division of labour, but this divide in labour does not appear to translate into difference in total physical activity.

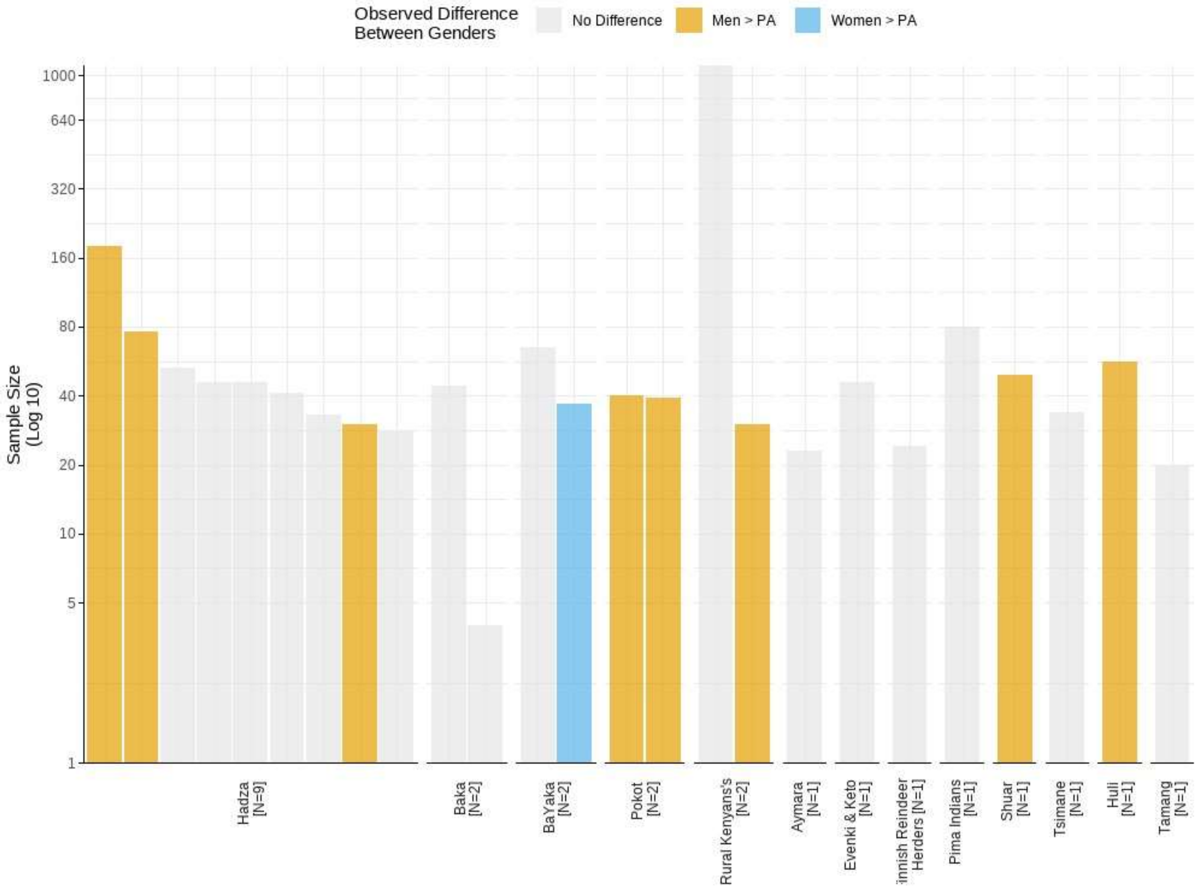


Figure 5-1: Summary of literature reporting physical activity in subsistence populations and their relative sample size (reported on a log scale). Populations are ordered by the number of studies detailing their activity. Colour represents any observed differences between genders in volumes of activity. Data for the figure draws from Table S C-1.

This observation is matched in other populations. When a measure of activity is based on lower body movements (either GPS or waist-worn accelerometer) men were more likely to have higher physical activity counts, as seen in studies of Shuar forager-horticulturalists of Ecuador,[128] Tsimane[127] forager-horticulturalists of Bolivia and Baka of Cameron.[129] Very little study of hunter-gatherers using a whole body measure of activity has been done in populations outside the Hadza, with the only identified study to date showing a reversal of previous findings. Though less than a day of activity was recorded, in a study of BaYaka adults (ages 22-67) by Sarma et al.,(2020)[126] women (n=20) spent a greater proportion of the recorded time in MVPA than men (n=17) (39.4% vs. 28.5%). Similar attenuation of the activity gap between men and women has been observed when a measure of physical activity energy expenditure is used amongst the Hadza ,[87] Evenki reindeer herders, Keto hunter-gatherers of Siberian Russia,[398] and Aymara pastoralists of Bolivia[399]

Overall, a division in the food stuffs prioritised by men and women appears to lead to differing behaviours but it is not clear if this leads to a difference in overall physical activity. In an egalitarian, monogamous society both men and women should share the costs of physical activity across all daily activities. While men's pursuit of mobile goods further away from camps[400] may lead to more time in moderate activity to cover more distance, women are likely engaged in active behaviours including foraging and digging, childcare, and camp maintenance which may lead to more time spent in light thresholds at the expense of sedentary behaviours. As such, in the present analyses there may not be a difference in overall activity (as measured by the mean acceleration) but may still be a difference in the patterns (as measured by time in each intensity).

5.1.3.2 Patterns of physical activity across the life course.

Of the studies identified, 14 included age as a possible factor affecting physical activity, 12 used an objective measure of physical activity, of which 10 found a significant relationship between age and physical activity. In the Hadza, a GPS measure of daily distance covered found a decrease with age.[79] This age-related downturn was only visible at ages greater than 45 years, but only 8 individuals (5 women) in the sample were older than 45. Yet a separate study of the Hadza did not find an association between reduced daily distances in old age and energy expenditure[87] though a small increase in total non-ambulatory time with age was observed in a study using thigh-worn accelerometers.[131] While in a GPS study of Baka[129] aged 20 years and under, the daily distance covered increased with age but overall physical activity did not increase with age, possibly indicating a change in behaviour into early adulthood with a focus on travelling greater distances. Studies that measured physical activity levels as a function of total energy expenditure found a mixture of effects. A small sample of Baka (Total n=4) found an age effect with a younger couple having a higher PAL than an older couple[393] whereas a study of the Aymara found no age effect.[399] A study of the Maasai, Kamba and Luo[401] found respiratory fitness to be greatest in the early to mid-20s, roughly peaking at the same time as Kaplan and Robson (2002) report net production to peak.[402]

Calorie provision (or primary productivity) may underlie trends in activity across the life course. Kaplan et al.'s (2000)[403] study of subsistence populations observed productivity to peak in early adulthood, which that remained high throughout the reproductive years before slowly declining over the post-reproductive lifespan. The overall trend with age appears similar to the aforementioned study of daily distances amongst the Hadza.[79] As such, productivity might not explain activity amongst adolescents and young adults as an increase in experience may facilitate an increase in productivity for the same energetic output, but equally a decrease in skill cannot explain a decline at older ages. Koster et al. (2020) add to this in their exploration of skill development.[206] Dependent on the complexity of the technology employed, skill peaked between the early 20s and the middle 30s, with a gentle gradient of improvement from the late teenage years and a gentle decline after the peak. This gentle rise and fall in skill meant that across the studied populations it took until age 56 for the skill level to reduce down to the levels of an average 18-year-old. Thus skill is unlikely to explain the decline in production observed by Kaplan et al,(2002).[402] Instead there may be an age-related shift in labour to indirect calorie provision (such as through child care[404], camp maintenance etc; where physical activity remains high but calorie returns occur via freeing other individuals to forage),[254,405,406] a decrease in physical function, or a mixture of the two.

Based on the existing literature, in the present study of the BaYaka it may be predicted that overall physical activity peaks during young adulthood in line with age related transitions to primary productivity.[200,206] Through adulthood physical activity may remain largely stable as productivity remains high before decreasing into old age as less time is invested in direct subsistence activities.

5.1.3.3 The effect of breast feeding and lactation on physical activity.

If instead women’s activity decreases in reproductive adulthood, it may be that the energetic costs of motherhood are at play. Studies in developed nations have highlighted the energetic costs associated with pregnancy[151,407] and lactation[408,409] which may require increased caloric intake or decreased output to maintain an energy balance. In a review of 31 studies of physical activity across pregnancy noted that there was a net, but not uniform, reduction in physical activity during pregnancy.[410] Hunter-gatherer mothers may also face strong incentive to reduce the amount of energy invested in physical activity[131] but this should be balanced against the necessity of continuing a level of provision and additionally in childcare. As cooperative breeders, women’s kin could act to increase the provision of mothers (allowing the mother to spend more time in childcare) which may reduce activity amongst mothers, or kin may take on childcare duties, freeing the mother to spend more time foraging, which could buffer against a reduction in activity.[404,405]

Only 3 out of the 23 studies identified explored the role of pregnancy or lactation on physical activity, of which the largest number of pregnant or lactating women included in one study was 15 (Pregnant = 5, Lactating = 10). Two of the three studies used the same data, as such only one is reported in detail here. A study in the Shuar of Ecuador[128] showed that women in their childrearing years had the lowest physical activity levels, while men with childrearing partners had higher physical activity levels than other men. However, no difference was found in the amount of active energy expenditure between pregnant or lactating women and non. Notably, the use a uniaxial accelerometer to estimate active energy expenditure could be compromised by incorrectly adjusting for pregnancy and lactation, as standardised calculations were used. A movement ecology study in the Hadza of daily distances covered also indicated a reduction during childrearing years but no significant direct effect was seen for pregnancy or lactation.[396] While a study of total energy expenditure, also in the Hadza,[79] found no difference in women with differing maternal statuses (Pregnancy=1, Lactating=7). A third study, using the same Hadza data in a new analysis, came to similar conclusions of no effect of maternal status on physical activity.[87]

5.1.3.4 Integration with market economies.

Though a transition to sedentary labour markets is proposed to underly a reduction in physical activity in post-industrial populations, [23,94,381] only two identified studies empirically explored the effect of market integration on physical activity within subsistence populations. The results are mixed; in a study of the Huli agriculturalists of Papua New Guinea, reduced activity was observed amongst more urban integrated women but no variation between rural and urban men was observed.[225] The authors suggest this is due to urban men swapping physically active farming for physically active wage labour, whereas women went from farming to domestic housework. Similarly, no association was observed between market integration and physical activity among the Tsimane[127] despite higher BMI's amongst market intergrated Tsimane.[128]

The effect of market integration on other energy related outcomes show interesting results. A study of growth in Hadza children found that those growing up on the edge of a town had a diet more consistent of cultivated goods.[383] Looking at their growth (both height and weight), those with the diet supplemented with cultivated goods had better scores for height and weight for age. In a study of Yucatec Maya agriculturalists, a different modern transition, a shift to mechanisation had a similar effect as children were engaged in less manual labour which was in turn associated with an increase in height, weight and adiposity without any observed change in diet.[411] As such, the effect of market integration may vary both between and within populations, dependent on both the form of labour replacing time spent foraging, and whether all individuals experience an equal behavioural transition following sedentarisation.

5.1.4 Limitations of existing hunter-gatherer research

5.1.4.1 Small sample sizes amongst small scale populations.

While studies of hunter-gatherers have attempted to explore the effect of gender, pregnancy, lactation and market integration on physical activity, owing to both the available technology and restricted sample sizes, the analyses lack the power required to draw confident conclusions. In the literature reviewed, only 4 studies had objective physical activity data for more than 50 individuals in a single hunter-gatherer population, of which 2 used an objective measure, with only 1 of these directly exploring physical activity. Once within group factors are included this becomes smaller still. Small samples limit the power to statistically identify differences, leading to increased risk of incorrectly accepting the null hypothesis (type II error). This may play into the lack of existing literature if null findings are less likely to be published. Owing to the nature of field work with hunter-gatherer populations the ability to obtain large samples is constrained, thus a key requirement to build confidence in the results is to expand the number of samples, both within and between hunter-gatherer populations.

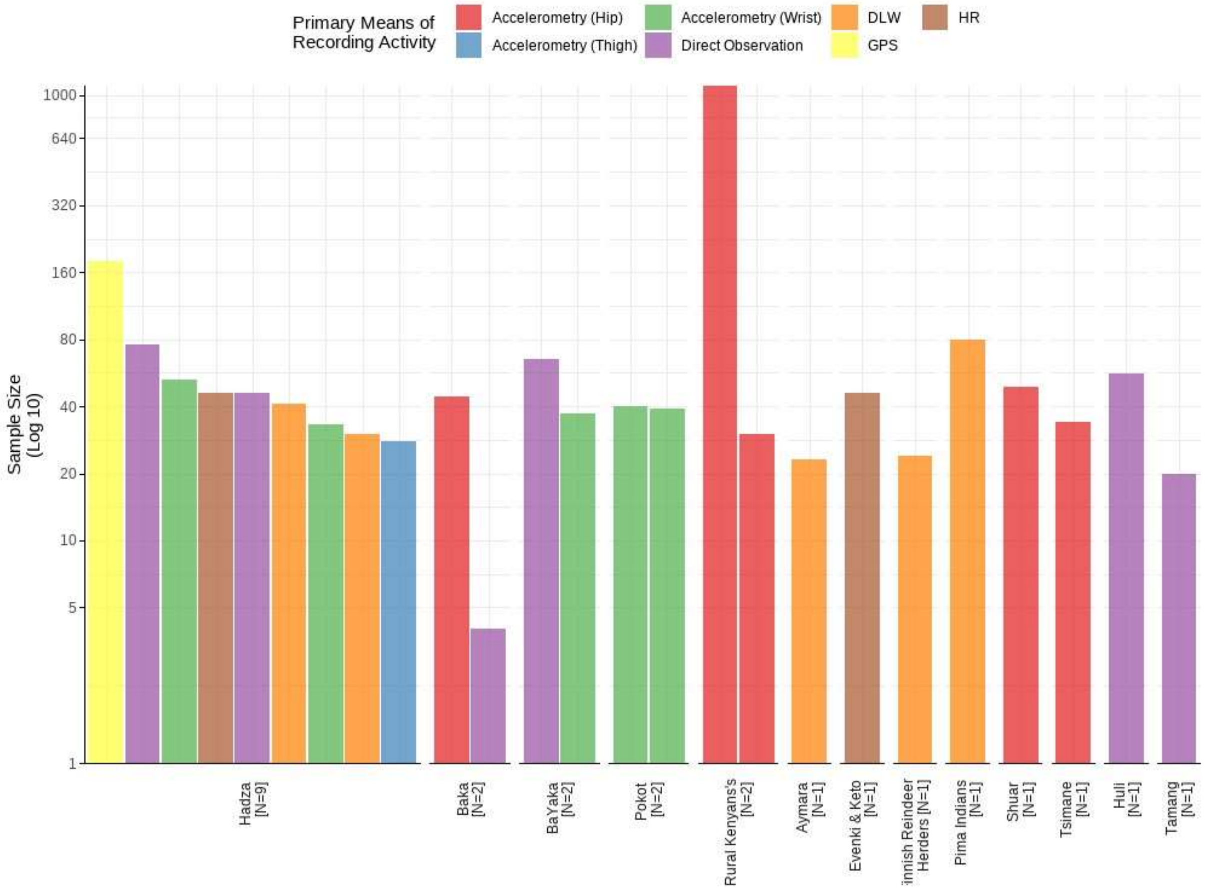


Figure 5-2: Summary of literature reporting physical activity in subsistence populations and their relative sample size (reported on a log scale). Populations are ordered by the number of studies detailing their activity. Colour represents the mode of activity recording. Where multiple means of recording activity are reported, preference is given to those that objectively report activity, followed by those that objectively report active energy expenditure, followed by observational data. Data for the figure draws from Table S C-1.

5.1.4.2 Methods of recording physical activity.

As discussed in section 2.1, the methods used to measure physical activity can have meaningful effects on the outcome. Further, in the growing field of hunter-gather physical activity the methods of accounting for physical activity have varied as technologies have improved.[118] The variation in methodology is shown in the identified literature, 7 studies used observation and focal follows, 6 used doubly labelled water, 4 used respirometry or gas exchange, 7 used heart rate monitors, 4 employed GPS devices with 10 using accelerometry, of which 1 was uniaxial thigh worn, 5 were uniaxial hip worn and 4 used wrist worn triaxial accelerometers (Table S C-1, Figure 5-2). The continuous improvements offered by developing technology mean there is little consistency in the methods employed, restricting the ability to confidently compare results between studies.[412,413]

Owing to this, the choice of methodology employed should best fit the questions being asked. As such, in the present analysis the aim is to quantify the daily activity patterns of BaYaka hunter-gatherers. Accelerometery offers the best available approach to understand both the overall volumes of activity and the patterning of activity between different intensities of behaviour in a free-living population.. A wrist-worn device suits the current question as its output should be less biased toward a given demographic group's behaviour, such as step-counts could be for hunter-gatherer men.

5.1.5 Summarising literature on hunter-gatherer physical activity.

Overall, there are a limited number of studies, dominated by studies of the Hadza, often using a variety of methods of recording physical activity, all with small sample sizes. Together, this led to inconsistent conclusions drawn for the variables of interest. The factor closest to having a consistent association with physical activity is that of age: across the studies reviewed the pattern of physical activity increasing from childhood into early adulthood and decreasing between early adulthood and older age is frequently reported. Though sex or gender was the most frequently explored factor of interest, most studies did not find an association between sex or gender and physical activity. The minority that did find a difference between men and women more often found men to undertake a greater volume of physical activity, but not exclusively so, with a short study of the BaYaka reporting higher levels of MVPA in women.[126] No association of maternal status was observed in the identified literature, but this could be resultant from the small samples. Only a few studies included maternal status, all of which had very small samples of women that were either pregnant or lactating. Finally, the effect of market integration on hunter-gatherer physical activity is notably understudied, with only two published pieces of work identified, both with contrasting conclusions: one found no effect while the other did for only one sex.

5.1.6 Research questions.

This chapter shall examine the pattern of daily physical activity in the BaYaka hunter-gatherers. Investigating the relative association of gender, maternal status, market proximity and age in a subsistence population.

I. Do men and women have differing patterns of activity? If so, does maternal status explain this effect?

II. In line with calorie returns, does physical activity peak in early adulthood?

III. Is physical activity reduced among individuals residing closer to town?

5.2 *Methodology*

5.2.1 Study population and data collection

As introduced in section 2.1.1 this study draws on data collected with the Mbendjele BaYaka of Congo-Brazzaville (Republic of Congo) in 2018. Three BaYaka camps in the forest of the Sangha river basin in northern Congo-Brazzaville were sampled of varying proximity to a town, one on the outskirts of the logging town (Sembola) and two in the forest (Longa (~50km from the town) and Njoki (~75km from the town))(Figure 2-1). At each campsite, participants were asked to wear a triaxial accelerometer (GENEActiv Original; Activinsights Ltd, Kimbolton, Cambs, UK, http://www.gene-activ.org/). These devices were chosen because they were robust, lightweight, waterproof, easy to use without impacting daily activities, and had a long battery life. All Individuals wore the device for a minimum of 24 hours, to include at least one complete day and night cycle.

In addition to the physical activity data, anthropometric data (including height measured in centimetres by stadiometer, weight measured in kilograms with portable scales, waist, and hip circumference (measured in centimetres with measuring tape), and information on pregnancy and breastfeeding status, (collected from self-report in interview) and age grouping were collected. As discussed in 2.1.1.3, accurately reported ages were not available for all individuals due to a lack of formal recording or tracking of ages amongst the BaYaka. As such age estimates for participants in the forest camps were used. Here these are presented as child (aged 3-15 years), young adult (16-25), mid-adult (26-50) and older adults (50+).

Across the three camps a total of 152 individuals were given accelerometers. After data processing, 5 of these had incomplete physical activity measures and were thus excluded and a further 10 were excluded as they had incomplete demographic and anthropometric data. Finally, 11 babies were removed from the analytical sample. This left 126 individuals in the sample (women=71, men=55) of which 88 (women=56, men=32) were aged between 16-50 years old (Table 5-1).

Table 5-1: Demographic Data of participants used in the analysis.

		All Ages		**Adults (Approx. 16-50)**	
	Level	Women	Men	Women	Men
n		76	58	59	37
Age Category (n)	Child	11	17		
	Young-Adult	41	26	41	26
	Mid-Adult	18	11	18	11
	Older Adult	6	4		
Village (n)	Sembola	38	18	38	18
	Longa	23	21	11	11
	Njoki	15	19	10	8
Maternal Status (n)	None	42		25	
	Pregnant	11		11	
	Breast Feeding	23		23	

5.2.2 Analysis of BaYaka physical activity.

Data processing followed the method outlined in section 2.3.2. Each individuals recording was collapsed to one entry per person, averaging their activity across the full recording to their mean daily activity. The outcome measures in this analysis are the mean amount of time per day spent in each intensity (Sedentary ≤ 50mg < Light ≤ 100mg < Moderate ≤ 400mg < Vigorous),[285,289] and the mean acceleration across the study period, measured in mg ENMO. The mean amount of time in Vigorous activity was positively skewed and was therefore log transformed at base 10 before data analysis (See Figure S C-1). Using linear regressions each is analysed separately in relation to the categorical predictor variables of gender, camp of residence and age category. In analysing differences by gender, the sample was restricted to reproductive age adults (16-50) (N=88). In examining the influence of maternal status, this sample was subset to women, with the binary variables of pregnancy and breast feeding. As before, the age range was restricted to adults of reproductive age (16-50) as beyond this age it was unlikely that pregnancy would have been possible (N=59).[414] In this study no adults over 50 years of age were recorded as pregnant or breastfeeding. Sampling in the village camp (Sembola) was restricted to those that had grown up in the camp, rather than relocated to it. As such, only young adults were included here so in testing the role of camp residency, only young adults were included (N=67).

5.3 Results

The average day for a BaYaka adult included 200 minutes of MVPA per day, at such volumes, the BaYaka exceed WHO recommended minimum amounts of *weekly* MVPA in less than 24hrs. Adults spent a further three hours in light intensity thresholds, meaning that over six hours of the BaYaka day was spent in active thresholds. Excluding sleep, a further 13hrs was spent sedentary. Together, this left adults with a mean acceleration across the recording period of 44.40mg. Across all ages, over 60% of participants exceeded 150 minutes of MVPA per day, with only one individual recording less than 30minutes of MVPA per day.

Table 5-2: Summary Statistics by Demographic Group.

	N	Mean ENMO (mg)	Sedentary (Min/day)	Light (Min/day)	Moderate (Min/day)	Vigorous[a] (Min/day)
Total (Adults 16-50)	96	44.4 (15.6)	773 (143)	178 (45.6)	185 (83.6)	14.0 (15.9)
Adult Women (Ages 16-50)	59	41.1 (13.9)	770 (152)	186 (48.8)	176 (87.3)	12.1 (15.3)
Adult Men (Ages 16-50)	37	49.7 (16.9)	778 (130)	165 (36.9)	199 (76.6)	16.8 (16.6)
Child (Ages 3-15)	28	45.4 (14.3)	758 (109)	180 (46.0)	152 (61.0)	17.4 (11.5)
Young adult (Ages 16-25)	67	45.9 (17.5)	748 (154)	173 (47.6)	197 (90.1)	16.8 (17.4)
Middle Adult (Ages 26-50)	29	41.0 (9.21)	830 (93.0)	189 (39.2)	157 (58.8)	7.35 (8.68)
Old Adult (Ages 50+)	10	33.3 (8.42)	892 (145)	198 (67.2)	104 (43.3)	3.39 (2.92)
Women Neither Pregnant nor Breast Feeding (Ages 16-50)	25	40.9 (14.4)	802 (156)	189 (53.7)	164 (84.4)	12.4 (18.2)
Pregnant (Ages 16-50)	11	38.7 (10.3)	753 (145)	199 (35.5)	173 (60.1)	8.16 (11.0)
Breast Feeding (Ages 16-50)	23	42.5 (15.1)	743 (150)	176 (48.7)	191 (101)	13.7 (13.7)
Sembola (Ages 16-25)	51	44.7 (16.7)	732 (151)	174 (51.2)	202 (90.0)	16.6 (18.0)
Longa (Ages 16-25)	10	45.6 (17.0)	835 (120)	184 (37.7)	156 (79.5)	11.5 (13.8)
Njoki (Ages 16-25)	6	42.1 (9.70)	826 (93.5)	181 (35.5)	166 (51.0)	8.84 (8.08)

Note: Reported as mean and standard deviation in brackets, to 3 significant figures. a = non-normally distributed values and thus reported as median and inter-quartile range.

5.3.1 Observed levels of physical activity in women and men BaYaka

Adult women (aged 16-50) recorded a lower mean acceleration than men (41.09mg vs 49.67mg). Within thresholds, a difference between the genders was observed in the amount of light activity (Table 5-3) with adult men spending less time each day in light activity thresholds (186 vs 165 min/day) and more time in vigorous activity compared to women (0hr12 vs 0hr17) (Table 5-2). At no other intensity did the amount of time notably differ between men and women, but men were observed to undertake slightly greater volumes of moderate activity than women (3hr18 vs 2hr54). Findings were similar upon adjustment for age category as covariates (Table 5-3).

5.3.2 Associations between age and levels of physical activity.

While young adults recorded the greatest mean acceleration (45.9mg) and the most time in moderate and vigorous activities (3hr17 and 0hr17 respectively), there was no difference in mean acceleration with children nor was there a difference between young adults and middle adults. With older adults spending the most time in sedentary activity (14hr52) and least amount of time in moderate (1hr43) and vigorous activity (0h03), there was an observed difference between young adults and older adults (Table 5-4) with older adults having a lower mean acceleration than young adults. In addition, young adults undertook less sedentary activity and more moderate and vigorous activity than the two older age groups. Young adults and children only differed in the mean amount of moderate activity undertaken. No difference was observed between young adults and any other age group in the mean amount of light activity recorded. Similar findings were observed after adjusting for gender (Table 5-4). Overall trends in activity with age were similar when only including those with accurately estimated ages (N= 44; Figure S C-2).

.

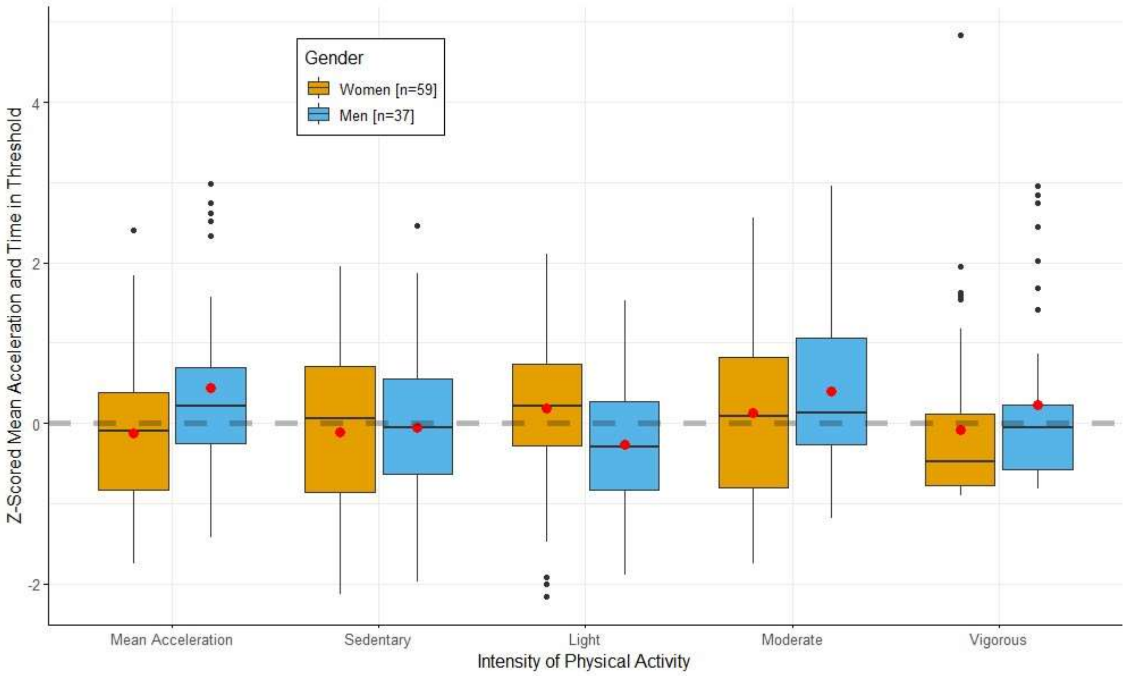


Figure 5-3: Z- score of the volume of time spent in each threshold of activity in BaYaka adults, grouped by gender. red point represents mean value.

Table 5-3: Linear model results for mean differences in physical activity measures per 1 standard deviation increase in women's physical activity volume. Repeated for each intensity threshold and mean recorded acceleration.

		N	Mean ENMO (mg)^{a}	Sedentary (Min/day)^{b}	Light (Min/day)^{c}	Moderate (Min/day)^{d}	Vigorous (Log$_{10}$ Min/day)^{e}
	Adult Women(Ages 16-50)	59	*ref*	*ref*	*ref*	*ref*	*ref*
Unadjusted	Adult Men (Ages 16-50)	37	**0.55** [0.15 – 0.95]**	0.05 [-0.36 – 0.47]	**-0.46* [-0.87 – -0.06]**	0.27 [-0.15 – 0.68]	**0.46* [0.05 – 0.87]**
Adjusted for Age Category	Adult Men (Ages 16-50)	37	**0.55* [0.15 – 0.95]**	0.06 [-0.35 – 0.46]	**-0.46* [-0.87 – -0.06]**	0.26 [-0.14 – 0.67]	**0.46* [0.06 – 0.86]**

Note: Reported as Standardized Coefficients and 95% confidence interval (β [95% CI]). *=p<0.05,**=p<0.01,=p<0.001. Full Regression Tables included in appendix; a =Table S C-2,b=Table S C-3,c=Table S C-4,d=Table S C-5,e=Table S C-6***

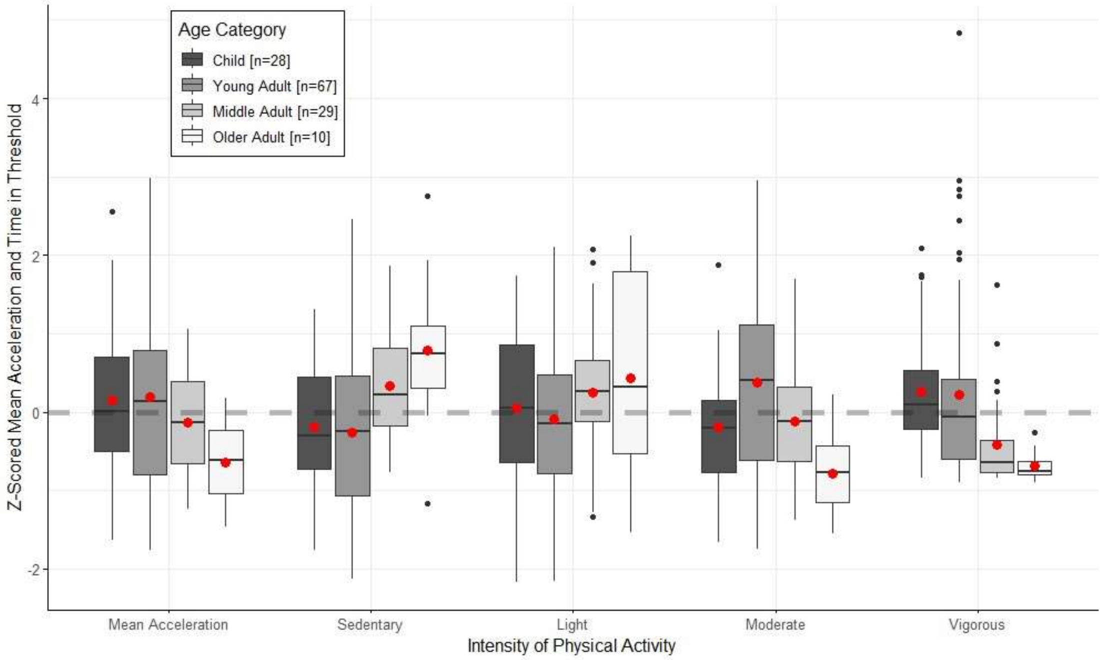


Figure 5-4: Z- Score of the Volume of Time Spent in Each Activity Threshold in BaYaka, Grouped by Age Category. Red Point Represents Mean Value

Table 5-4: Linear model results for mean differences in physical activity measures per 1 standard deviation increase physical activity volume in Young Adults. Repeated for each intensity threshold and mean recording acceleration.

		N	Mean ENMO (mg)[f]	Sedentary (Min/day)[g]	Light (Min/day)[h]	Moderate (Min/day)[i]	Vigorous (Log$_{10}$ Min/day)[j]
Unadjusted	Child (Ages 3-15)	28	-0.03 [-0.47 – 0.41]	0.07 [-0.35 – 0.50]	0.14 [-0.31 – 0.58]	**-0.56** [-0.98 – -0.14]**	0.35 [-0.07 – 0.77]
	Young adult (Ages 16-25)	67	*ref*	*ref*	*ref*	*ref*	*ref*
	Middle Adult (Ages 26-50)	29	-0.32 [-0.75 – 0.11]	**0.59** [0.17 – 1.01]**	0.34 [-0.10 – 0.78]	**-0.49* [-0.91 – -0.08]**	**-0.51* [-0.92 – -0.09]**
	Old Adult (Ages 51+)	10	**-0.83* [-1.49 – -0.17]**	**1.03 ** [0.39 – 1.67]**	0.52 [-0.15 – 1.19]	**-1.16*** [-1.79 – -0.52]**	**-0.97** [-1.60 – -0.34]**
Adjusted for gender	Child (Ages 3-15)	28	-0.13 [-0.57 – 0.30]	0.04 [-0.39 – 0.47]	0.23 [-0.21 – 0.67]	**-0.61** [-1.04 – -0.18]**	0.26 [-0.15 – 0.68]
	Middle Adult (Ages 26-50)	29	-0.31 [-0.74 – 0.11]	**0.59** [0.17 – 1.01]**	0.33 [-0.33 – 0.76]	**-0.37* [-0.91 – -0.08]**	**-0.50* [-0.91 – -0.10]**
	Old Adult (Ages 51+)	10	**-0.83* [-1.48 – -0.19]**	**1.03** [0.39 – 1.67]**	0.52 [-0.13 – 1.18]	**-1.16*** [-1.79 – -0.53]**	**-0.97** [-1.59 – -0.36]**

Note: Reported as Standardized Coefficients and 95% confidence interval (ß [95% CI]). *=p<0.05,**=p<0.01,=p<0.001. Full Regression Tables included in appendix; f =Table S C-7,g=Table S C-8,h=Table S C-9,i=Table S C-10,j= Table S C-11***

5.3.3 Association between pregnancy and breast feeding in BaYaka women.

Using absence of pregnancy and breast feeding as reference, neither pregnant nor breastfeeding individuals were observed to differ in the mean amount of time spent at any intensity nor affect the mean acceleration during the recording period (Table 5-5). No differences were observed at any threshold or mean acceleration in the adjusted model with the inclusion of age category and village. Though large confidence intervals and small sample sizes may obscure a loose trend of decreasing sedentary behaviours amongst mothers exchanged with time in moderate intensities. Clustering both pregnant and breastfeeding individuals together to test any maternal status vs. none did not lead to any meaningful change in the results (Table S C-17).

5.3.4 Physical Activity Patterns Between Campsites in Young Adults.

At no intensity was there an observed difference in the mean daily time spent at that intensity found between young adults in the three campsites, nor was any difference observed in the mean acceleration across the recording period (Table 5-6). The lack of differences between young adults in each campsite remained after the inclusion of gender as a covariate in the adjusted model. Repeating the analysis with both forest camps combined together did not lead to any meaningful change in the results (Table S C-23).

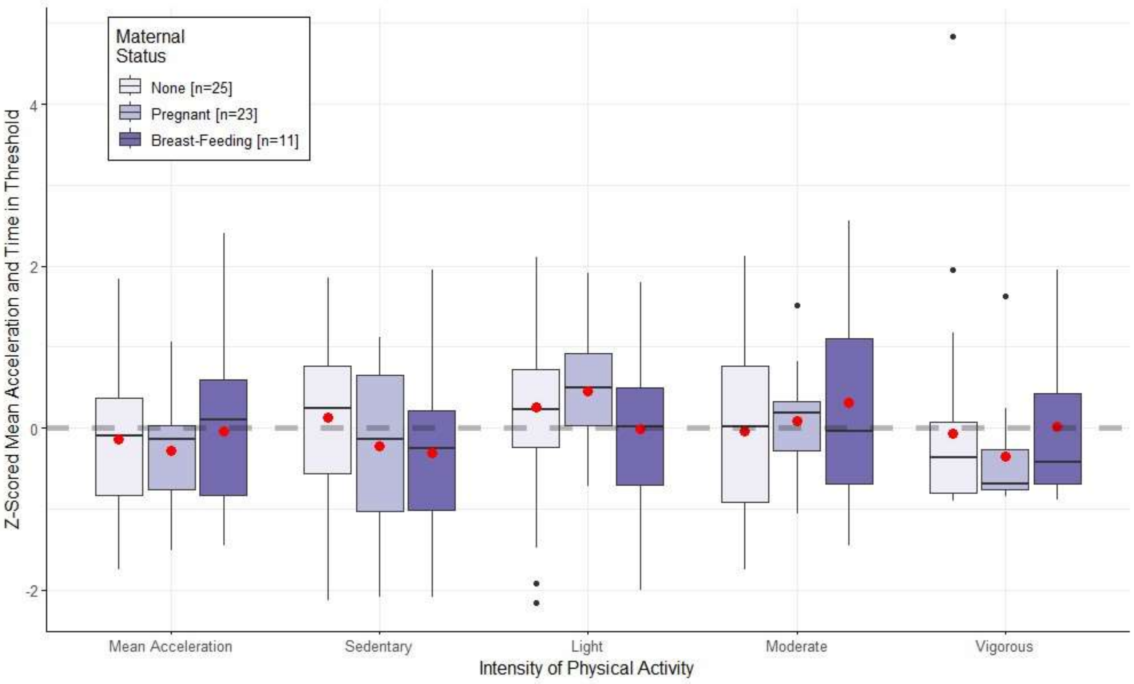


Figure 5-5: Z- Score of the Volume of Time Spent in Each Activity Threshold in BaYaka Women of reproductive age, Grouped By Reproductive Status. Red Point Represents Mean Value.

Table 5-5: Linear model results for mean differences in physical activity measures per 1 standard deviation increase physical activity volume in women neither pregnant nor breast feeding. Repeated for each intensity threshold and mean recording acceleration.

		N	**Mean ENMO (mg)^{k}**	**Sedentary (Min/day)^{l}**	**Light (Min/day)^{m}**	**Moderate (Min/day)^{n}**	**Vigorous (Log$_{10}$ Min/day))^{o}**
	Women Neither Pregnant nor Breast Feeding (Ages 16-50)	25	*ref*	*ref*	*ref*	*ref*	*ref*
Unadjusted	Pregnant (Ages 16-50)	11	-0.16 [-0.89 – 0.58]	-0.32 [-1.05 – 0.40]	0.20 [-0.52 – 0.93]	0.11 [-0.62 – 0.84]	-0.03 [-0.76 – 0.70]
	Breast Feeding (Ages 16-50)	23	0.12 [-0.47 – 0.70]	-0.39 [-0.97 – 0.19]	-0.26 [-0.84 – 0.32]	0.31 [-0.27 – 0.90]	0.31 [-0.28 – 0.89]
Adjusted for Age Category and Village	Pregnant (Ages 16-50)	11	-0.17 [-0.93 – 0.59]	-0.34 [-1.05 – 0.37]	0.07 [-0.67 – 0.82]	0.09 [-0.63 – 0.82]	-0.02 [-0.76 – 0.72]
	Breast Feeding (Ages 16-50)	23	0.10 [-0.93 – 0.71]	-0.30 [-0.87 – 0.27]	-0.32 [-0.91 – 0.27]	0.24 [-0.34 – 0.82]	0.27 [-0.33 – 0.86]

Note: Reported as Standardized Coefficients and 95% confidence interval (ß [95% CI]). *=p<0.05,**=p<0.01,=p<0.001. Full Regression Tables included in appendix; k=Table S C-12, l= Table S C-13, m= Table S C-14, n= Table S C-15, o= Table S C-16.***

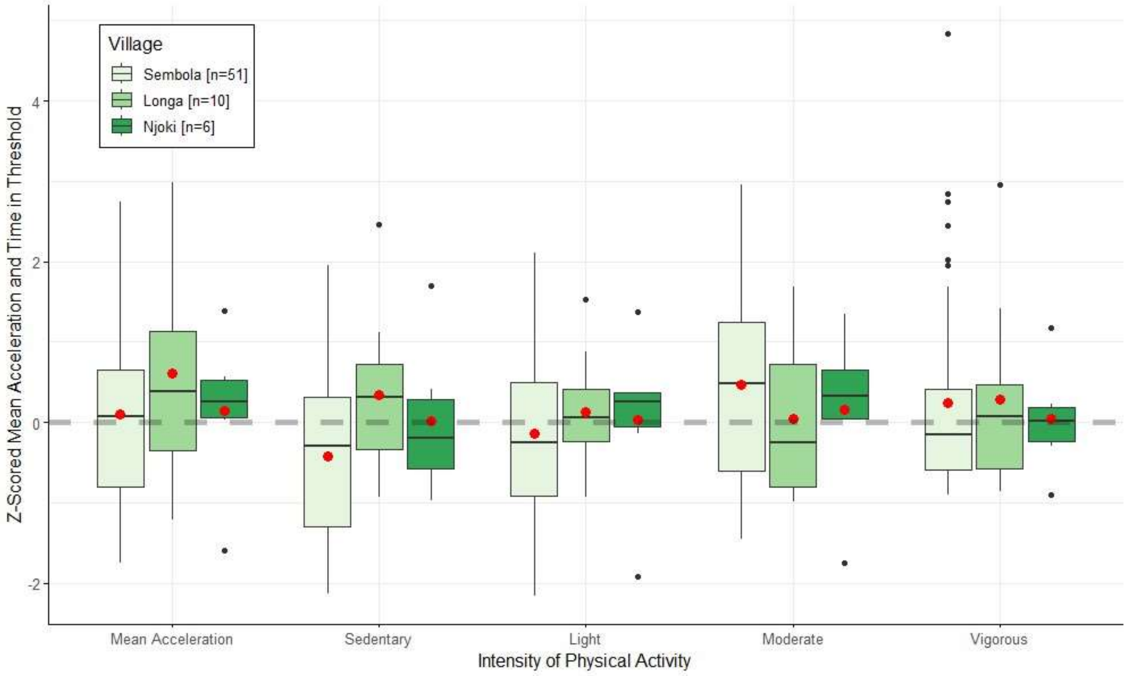


Figure 5-6: Z- Score of the Volume of Time Spent in Each Activity Threshold in BaYaka Adults, Grouped by Campsite (In Ascending Order of Distance from Pokola). Red Point Represents Mean Value

Table 5-6: Linear Model results for mean differences in physical activity measures per 1 standard deviation increase physical activity volume in Sembola. Repeated for each intensity threshold and mean recording acceleration.

		N	**Mean ENMO (mg)^{p}**	**Sedentary (Min/day)^{q}**	**Light (Min/day)^{r}**	**Moderate (Min/day)^{s}**	**Vigorous (Log_{10} Min/day)^{t}**
	Sembola (Ages 16-25)	51	*ref*	*ref*	*ref*	*ref*	*ref*
Unadjusted	Longa (Ages 16-25)	10	0.44 [-0.25 – 1.13]	0.67 [-0.01 – 1.35]	0.27 [-0.43 – 0.97]	-0.38 [-1.08 – 0.31]	0.08 [-0.62 – 0.78]
	Njoki (Ages 16-25)	6	0.04 [-0.237, 0.260]	0.38 [-0.47 – 1.23]	0.18 [-0.69 – 1.05]	-0.28 [-1.14 – 0.59]	-0.26 [-1.14 – 0.61]
Adjusted for gender	Longa (Ages 16-25)	10	0.30 [-0.38 – 0.98]	0.67 [-0.02 – 1.37]	0.37 [-0.33 – 1.07]	-0.46 [-1.17 – 0.24]	-0.04 [-0.74 – 0.66]
	Njoki (Ages 16-25)	6	0.05 [-0.79 – 0.89]	0.38 [-0.47 – 1.24]	0.17 [-0.69 – 1.03]	-0.27 [-1.13 – 0.59]	-0.25 [-1.11 – 0.60]

Note: Reported as Standardized Coefficients and 95% confidence interval (β [95% CI]). *=p<0.05,**=p<0.01,=p<0.001 Full Regression Tables included in appendix; p=Table S B-18, q=Table S C-19 , r= Table S C-20, s=Table S C-21 , t= Table S C-22.***

5.4 Discussion

5.4.1 BaYaka physical activity patterns.

The BaYaka were highly active. Amongst adults (aged 16-50), for whom the WHO would recommend a minimum volume of 150 minutes of MVPA *per week*,[5] their daily volume approached 200 minutes *per day*. Despite this, BaYaka still spent most of their time in sedentary behaviours. When the BaYaka were active, most of their time was spent in light and moderate activities, forming roughly 3 hours each, with very little time spent in vigorous intensity activities. As the intensity of activity is positively associated with the energy outlay required for it,[82] reducing the intensity of activities may preserve more energy to be spent on other processes. As such, the observed pattern of physical activity reflects the required amounts of movement in their hunting and gathering niche to meet their obligations of provision, care, socialisation, and mating effort.

Overall, the mean acceleration observed in adults (women =41.1 ± 13.9, men = 49.7 ± 16.9) falls in the range observed amongst the Hadza of Tanzania[224] (women = 50.4 ± 3.5 mg, men = 43.2 ± 2.9 mg) and in excess of values observed in an urban sample of 30 year old Brazilians[285] (women = 32.7 ± 0.5 mg, men = 37.8 ± 0.7 mg) and a sample of Britons aged 45-54 (women = 31.2 ± 8.7 mg, men = 31.1 ± 9.7 mg).[415] Despite varying ecologies and behaviours, this supports the view that a generalised hunter-gatherer lifestyle is notably more active than the lifestyle of people living in industrialised nations. Yet, like findings in the Hadza,[131] the BaYaka here show high volumes of sedentary activity, supporting the view of a trade-off between a mode of living that is highly active but maximising time spent sedentary wherever possible.

A parallel of this in the post-industrial world is seen in highly trained athletes, a meta-review of 13 studies observed athletes to show both above average volumes of moderate to vigorous physical activity (estimated at around 100 minutes per day) and above average volumes of sedentary behaviour.[416] Though little identified research has employed a similar methodology amongst athletes, a validation study with 35 experienced recreational runners observed daily accelerations above 41mg to occur on days of training (Average Weekly running distance = 22miles).[417]

A validation test of the GeneActiv device conducted as part of this research noted that to approach similar mean accelerations to the BaYaka (~50mg) would require either an additional 10km of running or 16km of walking on top of a sedentary working day to approach BaYaka values (Figure 5-7). Together, this suggests that ancestral human populations would likely have been highly active, with modern sedentary populations presenting a notable shift from these active lifestyles.

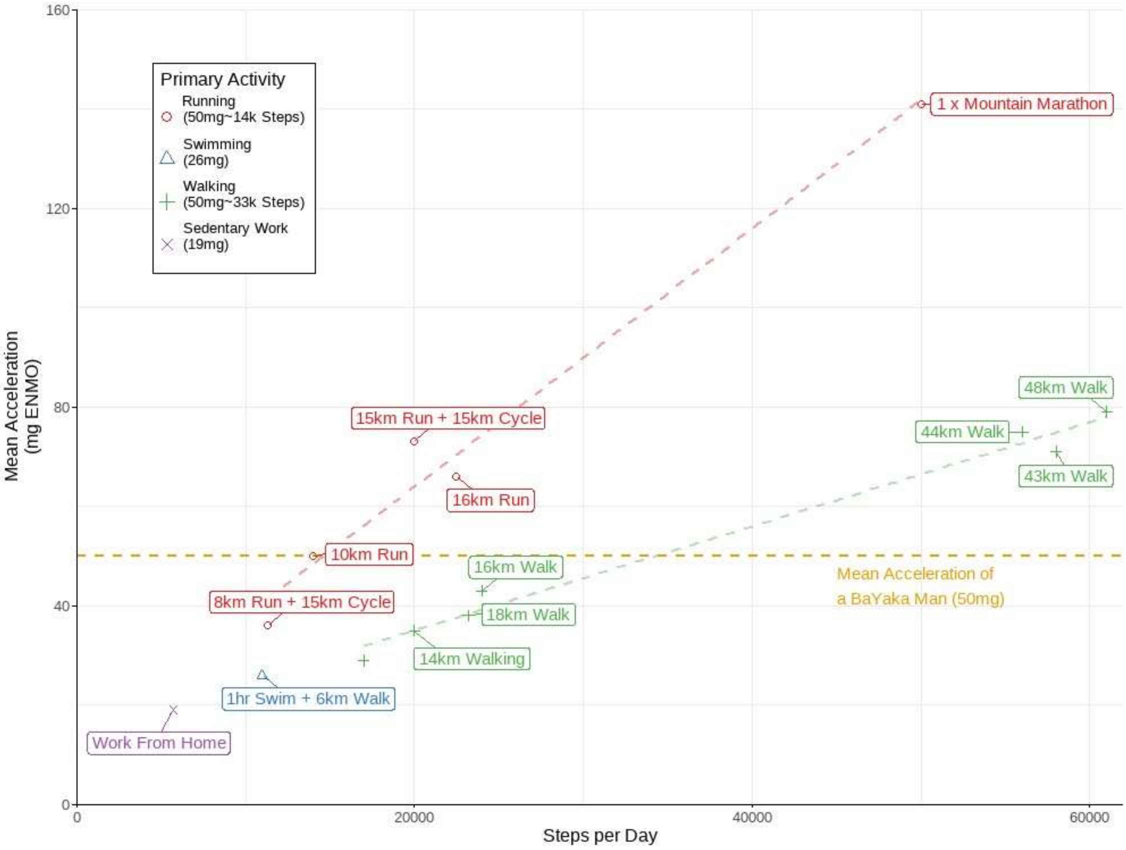


Figure 5-7: Mean acceleration as recorded by the author while wearing a GeneActiv wrist-worn accelerometer. All values represent the mean acceleration over a 24hr midnight to midnight period. Excluding the three walks at approximately 60,000 steps and the run at 50,000 steps, all activity was recorded on days with office work being the primary form of activity (between the hours of 9am and 5pm). Steps and distance were recorded using a Garmin Forerunner 945, with accelerations calculated using a GeneActiv in the same manner as employed amongst the BaYaka.

5.4.2 Gendered activity patterns amongst the BaYaka.

Among the BaYaka, men and women showed different patterns of physical activity, with women undertaking more light activity and less vigorous activity. While no difference was observed at any other intensity, the total time in active thresholds (light, moderate and vigorous) appears balanced across the day (F:6hr15 vs M:6hr20/day). As such, the observed shift toward lower intensities may underlie the lower mean acceleration seen in women (41mg vs 50mg in men), but the implication of this is that women are spending proportionally less energy per day on physical activity than men. This follows some previous findings in hunter-gatherers that showed men engaged in more daily activity than women,[79,229] but unlike these, no difference was found in moderate activities. Given the lack of effect of maternal status (discussed below), it may instead be that across the recording women's general activities are broadly as active than men's, but men engage in a greater proportion of the most intensive activities which drives the variation by gender. Despite the divide in activity between men and women mirroring the direction seen in post-industrial populations, BaYaka women were still highly active, undertaking over three hours of MVPA per day.

5.4.3 Activity patterns of BaYaka mothers

Contrasting some studies carried out in post-industrial populations, neither gestation nor lactation reduced total physical activity amongst reproductive age BaYaka women. While the evidence for a change in activity amongst post-industrial women is mixed, where a change in activity is observed it was always a decline with pregnancies progression.[418] Amongst the BaYaka, although non-significant, it appears that both pregnancy and lactation might decrease the total time spent sedentary, with compensatory increases in moderately intensive activities (Table 5-2).

These results highlight the importance of physical activity to BaYaka mothers. A potential explanation of this lack difference between women is that amongst this population there is no stage of life in which adults are not engaged in childcare. Women who are still actively involved in caring for weaned children, but not currently pregnant or lactating would be part of the 'non' grouping in this analysis. Equally, it may be that the involvement of alloparents may free mothers to resume foraging and subsistence behaviours sooner. In ecologies where women's foraging efforts requires a degree of skill that children do not possess, or strength that older women no longer possess, it may make sense for reproductive age women to resume foraging with these other two groups assuming childcare responsibilities.[200,254,404,405] Such a division of labour across the life course may also help to explain the reduced activity amongst older BaYaka. Further it could be that to compensate for the energetic burden upon (expectant) mothers, men increase their activity to provision additional calories. This could also underlie the observed difference between men and women during reproductive ages. Such a pattern was observed in the Shuar of Ecuador with reproductive aged men increasing their physical activity when their partners were pregnant or lactating.[128]

While this may explain why the behaviours are not different between pregnant, lactating and non-pregnant/lactating, the potential double energetic burden for pregnant and lactating women would remain.[146,151] Lactational amenorrhea is observed in the BaYaka, with a local understanding that women cannot conceive until their children are weaned, with an accompanying taboo on having sex before any nursing child is weaned.[400,419] As such, the energy burden of a BaYaka lifestyle and being pregnant or presently lactating may be being traded off against future reproduction.

While the energy spent on reproduction is theoretically increasing,[146] pregnant and lactating BaYaka women are maintaining a daily level of MVPA (Pregnant: 3h01 per day, Breast-feeding: 3h25 per day) far in excess of the 150 minutes per week recommendation that pregnant post-industrial women frequently fail to meet.[418] As physical activity through gestation has been associated with a series of beneficial outcomes for both mother and child, medical practitioners often place a focus on ensuring women remain active throughout gestation.[420] As such, amongst post-industrial populations with more liberal access to calories, the energetic costs of gestation seem unlikely to underpin any declines in activity.[418] Instead, socio-cultural factors may influencing activity patterns amongst post-industrial mothers. Amongst others, this could include a lack of available kin in to provide support and childcare in contemporary nuclear families, restricting mothers ability to return to pre-maternal activity levels.[421,422]

5.4.4 Patterns of physical activity across age groups.

Young adults were found to be the most active age group in this study, matching the expected association of increased productivity and physical activity levels.[206] With BaYaka subsistence dependent on hunting, trapping, foraging and fishing, increasing calorie returns should be driven by either more time engaged in these behaviours or improved efficiency resulting in greater returns per unit of time. With middling adults observing lower levels of activity than young adults, it is unlikely that changes in skill level can singularly explain Koster et al's., (2020) observations.[206] Thus, the time invested into calorie acquisition must underlie some of this change. For the BaYaka, they will typically become parents for the first time during young adulthood.[141,414] As such, it could be that, as discussed above, young men in particular are increasing their amount of provisioning and therefore activity, driving the disparity with both older men and similarly aged women.

BaYaka young adults being the most active contrasts to observations in post-industrial populations. In Chapter 3 it was observed that post-industrial youth became less active as they approached early adulthood, with similar observations in the cross-sectional NHANES sample (Figure S C-2). Highlighting the cultural drivers of activity, where a

BaYaka transition to direct productive through foraging or hunting requires more activity, and American transition to productivity through wage labour can act to release pressures to be active.[94]

No difference was observed in the mean acceleration between children and young adults, implying that children are as active as young adults are. Discussed further in section 2.1, while the behaviours children are engaging in are different to young adults, play often mimics gender-specific adult activities.[202] Additionally the transition from play to productivity occurs before 16, thus within the ages included in childhood in the present study.[200] Together, this may help explain the lack of differences between children and young adults as the physical activity required for play mimics the activity required for adult hunter-gatherers, and the transition to foraging may require as much activity but be less efficient while this skill is being developed.[166,206]

In this study, older individuals reduced the amount of time spent in moderate and vigorous activity, replacing this with more time spent sedentary compared to young adults, but did not differ in their volumes of light intensity activity. A possible explanation is a change in the behaviours undertaken, replacing some time in activities that typify earlier adult activity (hunting/foraging), replacing these with less intensive activities such as childcare, or activities that have their intensity undervalued with accelerometers compared to foraging, such as carrying firewood or water to camp, as was observed to form a large part of older women's activity. While this mirrors trajectories of activity in aging post-industrial populations (see Figure S C-2 for cross-sectional observations in the 2013 NHANES sample),[423] elderly BaYaka on average still exceeded WHO weekly guidelines within two days.

5.4.5 Market integration and movement.

Market integration was not seen to alter physical activity patterns within this population. It was hypothesised that the young adults in the camp adjacent to town (Sembola) would reduce their total physical activity (mean acceleration), however no difference in the activity patterns or total physical activity was observed. The BaYaka living in the town still go on daily foraging trips but they also engage in wage labour more frequently than the BaYaka from forest camps, and have greater access to markets and healthcare through the free hospital in Pokola.[188,194] As such, it may be that the behaviours engaged in are different, but these do not result in a change of overall physical activity here. However, it may be that with time and further market integration the effects start to appear, whether that be due to decreasing reliance on forest goods or increasing mechanisation, as seen to increase growth in the Yucatec Maya of Mexico.[411]

Sampling in Sembola was restricted to young adults that had grown up in the camp, thus, not explored within this analysis is whether there are any age specific effects. In the Huli of Papua New Guinea, the effect of market integration was only seen amongst women,[225] highlighting that any effect of market integration on physical activity may not affect all individuals equally. Amongst more settled BaYaka, it may be that young adults remain active for the purposes of productivity, leaving the potential that those less active, namely older adults, would provide a greater marker of behaviour change with market integration.

5.4.6 Energetic trade-offs cannot fully explain transitions in BaYaka activity.

While no direct measures of energetics were collected, the general trend of activity peaking in early adulthood before tailing into older age appears to follow predictions from a simple model of the energy available for physical activity being highest when proportional basal metabolic rates are lowest.[86,146] However, proportionally, basal metabolic rates should be highest in childhood,[146] yet this population did not observe a meaningful difference between child and adult activity levels. A simple model would also predict that reproductive status would alter activity levels but no support for such an interpretation is found amongst this sample.

A likely caveat to a simple trade-off model is that the energetic return from activity on a given day may take years to occur. In the case of children here, failing to be active when young may compromise their ability to develop the skills needed to forage effectively as adults.[166] However, the energy invested into movement by children could help explain the reduced growth amongst the BaYaka.[141] This would fit with Migliano's[141] predicted mechanism of reduced growth in Pygmy populations being an adaptive response that protects reproduction. Though Migliano argues against calorie restriction underlying reduced growth, these results, with a view of constrained energy budgets, may suggest that the restriction on calories comes not from the amount of energy procured from the environment, but from how much is being spent in other avenues.

5.4.7 BaYaka insights into physical activity mismatch.

The present results highlight that the BaYaka, and hunter-gatherers more broadly,[24] lead highly active lives. As discussed in section 1.2.3.2 and presented in Table 1-1, this high level of activity has been associated with a lower burden of non-communicable diseases.

While multiple aspects of their ecology and behaviour likely contribute to these reduced rates of disease, persistently high levels of physical activity across the life course should also contribute to their health and development.[25] With volumes of activity shared amongst extant hunter-gatherer groups, it is likely that the ancestral behavioural suite of all extant humans was highly active.[24] Maintaining such actives lifestyle requires the development and maintenance of a body that can handle large amounts of movement.[24] Included in this is an effective cardio-respiratory system that can deliver energy and oxygen to muscles and remove waste products efficiently, a skeleton that can handle the stresses of movement, as well as a body that can store, transport, and access the energy required for movement. Further, for factors more afferent from the direct mechanisms of movement, evolution of these traits would have occurred with the backdrop of highly active lives, and the trade-offs it requires.

5.4.8 Strengths

Amongst physical activity research, this study presents one of the largest samples in a single hunter-gatherer population. In using an objective measure of physical activity across all intensities of activity, this research provides a reference point for activity volumes in the BaYaka of Congo-Brazzaville. Though the sample sizes are low compared to the epidemiological datasets that are included within this thesis, a larger sample size compared to other studies of physical activity in subsistence populations (Table S C-1), allowed for an examination of differences between campsites, ages, and maternal statuses, which few studies have been able to do. For instance, in examining the role of maternal status, the sample includes over twice as many pregnant and lactating women (N=34) as the next largest sample collected amongst the Shuar by Madimenos et al., (2011) (N=15).[128] Further, in the present study, all intensities of activity are included, allowing for an examination of how differing behaviours are traded off against each other. Where previous studies have focused solely on MVPA, they fail to account for changes in sedentary behaviours, or light intensity activities that still have a meaningful impact on health.[424]

5.4.9 Limitations

The present analysis is one of the largest studies of a single hunter-gatherer population, but it is still small when compared to the epidemiological datasets included in this thesis, particularly when subset. As such, these comparatively small sample sizes likely reduce the confidence that can be placed in the results seen. This could result in wider confidence intervals reducing the likelihood of observing an association with a factor, or outliers skewing marginal effect sizes.[425] However, significance was reached in instances where a trend was observed (such as activity in older age, or between men and women), and where an effect was not observed (maternal status and camp of residence) there was no notable trend. Though this does not negate the effects of a small sample, given that some subgroup analyses here exceed the sample size in the existing literature, this analysis makes a notable addition to the existing literature and allows for quantitative analysis of within group factors that have not been possible in other studies.

Accelerometry was collected for at least 24 hours for all individuals, with a mean recording length of 57 hours up to a maximum of 119 hours. This length of time was chosen to maximise the total number of participants over the study period, but this assumes that the behaviours engaged in on one day reflect the behaviours of all days. While this may hold for many individuals, and other studies of hunter-gatherer physical activity have made the same assumption, it may be that individuals alternate their behaviours across multiple days. Of note to this study, is the lack of differences between the town camp and the forest camps. While the individuals in Sembola do engage in wage labour and market activities,[188] they also continue to hunt and gather in the forest. As such, it may be that on the days of recording individuals partook in more foraging than would appear normal over a longer recording period. However, this limitation does not negate the hypothesis that individuals would focus their foraging on more easily accessible goods or those with a higher return for energy spent.

A noteworthy limitation of accelerometers is their inability to represent resistance-based activities (such as lifting or holding a weight). Amongst the BaYaka, it could be that women are as active, but a greater proportion of their activity is load bearing (such as carrying a child) which would be under-represented in wrist-worn accelerometry. This could also underlie the lack of differences observed between children and young adults if a greater volume of activity for one age group involves weight bearing.

Away from settlements which may formally record births, the BaYaka do not typically track their age. As such, this study used age as a categorical variable due to the limited number of individuals with a reliable age estimate. Using groups does therefore leave the possibility that individuals are not equally distributed within each age grouping. It is therefore a possibility that individuals are either closer or further apart in age than the midpoints of each age category would imply, which may have altered the likelihood of observing variation between age groups. Notably for children, this bands several developmental stages together into the childhood group, encompassing individuals that are starting to move, to those that are nearly adult. Across this age span individuals are going through numerous behavioural transition.[200,202] Chapter 6 aims to address some of these issues in examining children's activity. There, using data collected in 2022, a longer recording amongst a smaller sample of children for whom ages could be accurately estimated is used to examine differences within an age group.

5.4.10 Conclusions and links to other chapters.

The BaYaka mode of subsistence was seen to be highly active and akin to other hunter-gather populations.[87] Exceeding WHO weekly guideline amounts in a single day[76] activity was highest amongst young adults, roughly peaking at a similar age as would be expected from both a life history (see section 1.2) and calorie return perspective.[206] Like post-industrial populations, there were marginal differences in overall activity between men and women, but these did not appear to be due to lactation or gestation, so instead may reflect a division of labour extending into a division in activity. Despite the contrast in activity seen with post-industrial populations, within the BaYaka the initial transitions to market integration do not appear to alter activity in young adults, but more work with other age groups is needed.

With the BaYaka's high volumes of activity being formed through childhood, using additional data collected in 2022 as well as a subset of the children from the 2018 collection with known ages, Chapter 6 provides a detailed examination of childhood activity in the BaYaka, and how adult patterns of activity are formed across childhood. Chapter 6 attempts to address some of the limitations here, namely through using a longer recording period, using age as an accurately estimated continuous measure, and makes direct comparisons with the US and UK. The BaYaka model of activity is formed by their ecology, and the necessary amount of activity to obtain enough calories, maintain social bonds, and sustain a hunting and gathering mode of life. As this imparts ecological pressures that may vary between differing populations, the role of ecology in physical activity patterns is discussed in section 1.2.3. A wider discussion on the role of physical activity is included in section 1.1. A discussion on the relative strengths and weaknesses in methods of objective physical activity measurement are included in sections 2.1.

Chapter 6 Distributions of physical activity in BaYaka children of Congo-Brazzaville

Main Objective: Objectively quantify patterns of physical activity in BaYaka children and how it varies by age in comparison to a UK and US dataset.

Background: The high prevalence of obesity and metabolic disease in post-industrial populations has been proposed to be a result of a 'mismatch' between highly sedentary lifestyles and bodies that evolutionarily adapted a physically demanding foraging lifestyle. Among contemporary foraging populations, daily volumes of activity among adults have been seen to exceed weekly volumes of activity seen in many post-industrial nations. Little, however, is known about the daily physical activity levels of children from foraging populations.

Methods: The physical activity patterns of 51 BaYaka children (Ages: 5-17 years) from Congo-Brazzaville were quantified using wrist worn triaxial accelerometers, with data collected in 2018 and 2022. The association of age and gender with physical activity were analysed using mixed effect models. In addition to overall activity levels, the variation in activity within and between days was also analysed. Throughout, patterns of activity were compared with children in the US NHANES dataset, and the British MCS dataset.

Results: For Bayaka children, the average day included three times the WHO recommended one hour of MVPA. This was over an hour more than British 14-year-olds, and resulted in a mean acceleration 15mg higher (49mg vs 34mg). For the BaYaka volumes of activity increased by 1mg or 11 minutes of MVPA for each additional year of age. BaYaka children observe a diurnal pattern of activity, with the primary sleep window occurring between 22:00 and 06:00. All children appear to wake up together, but older children went to sleep later.

Conclusions: These results demonstrate the high levels of activity required to grow up in a foraging niche and provide an important point of reference in our understanding of childhood physical activity. Despite gendered activities, boys and girls engaged in comparable levels of activity. Reflecting observational studies, the transition toward adult behaviours was associated with an increase in physical activity. However, the inverse association is seen in post-industrial populations, consistent with the view that drivers of contemporary inactivity are likely to be socio-cultural.

6.1 Introduction

Globally, children in post-industrial populations are chronically inactive,[426] putting them at increased risk of poorer health outcomes in both the short and long term (Discussed further in section 1.1.2).[1,2,76] While there is some variation in physical activity between children from differing developed nations (See Chapter 4), the scale of variation is much smaller than has previously been observed between adult hunter-gatherers and post-industrial populations. Similarly in both Chapter 5 and in Raichlen et al's., (2017) of Hadza physical activity, adults were observed to undertake a daily volume of activity that exceeded weekly activity guidelines.[76,130] While activity in adult subsistence populations has been studied, little research has been dedicated to examining the physical activity patterns of children in these populations, and the scale of difference with post-industrial populations. While individuals under the age of 18 have been included in the samples of some studies, only two identified studies have focussed on quantifying patterns of activity in children (Figure 6-1). The first, a study of spatial ecology in Baka children, observed daily step counts to be in excess of 20,000 steps.[129] A second which aimed to translate observational data into METs (See Section 2.2.1) noted an increase in MVPA at the expense of time in light intensity activity.[229]

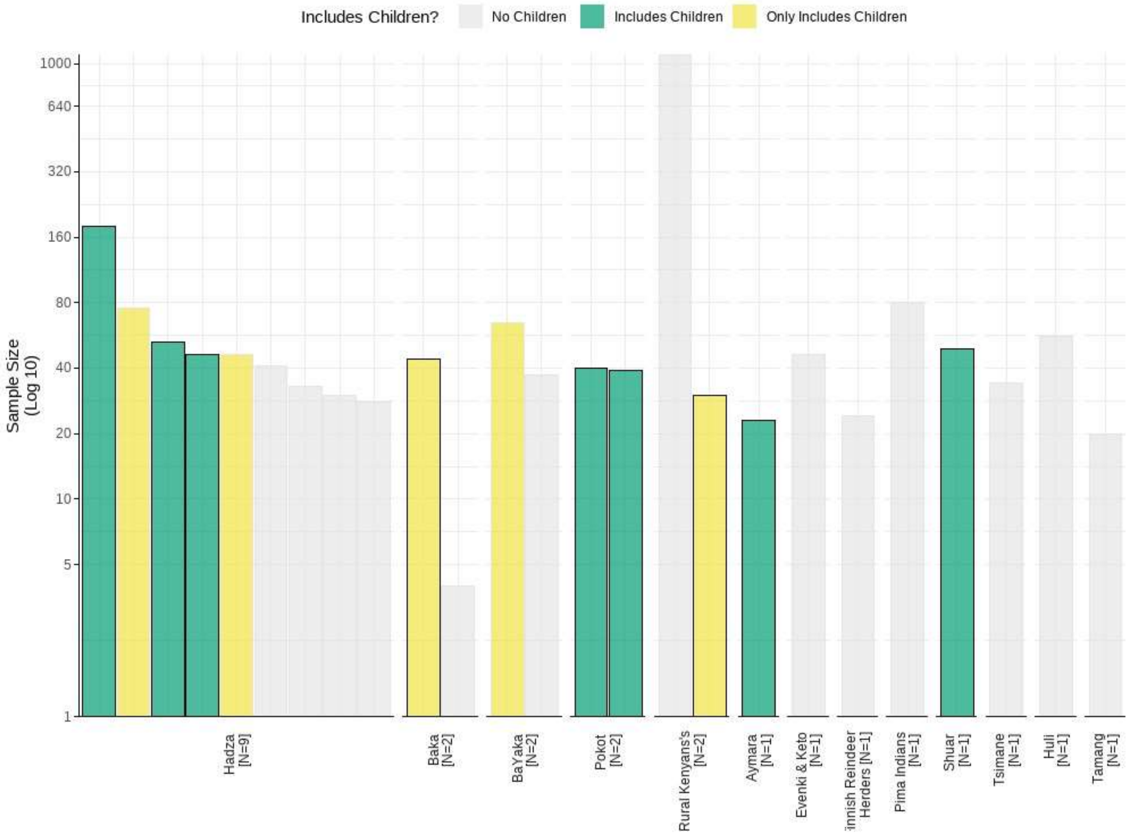


Figure 6-1: Summary of literature reporting physical activity in subsistence populations and their relative sample size (reported on a log scale). Populations are ordered by the number of studies detailing their activity. Colour represents the ages of included individuals. Where a study includes children (Aged under 18), bars outlined in black indicates where the study also uses an objective measure of physical activity. Data for the figure draws from Table S C-1.

6.1.1 Ethnographic observations of hunter-gatherer behaviour throughout childhood.

In Chapter 5 the collective group of 'children' were observed to be highly active, but lacking in both detail and sample size, it was not possible to examine the trajectory from altricial infants to active adults. Observational and ethnographic studies elucidate the behavioural transitions throughout childhood, which may help develop an expected pattern of activity. As discussed in sections 1.2.3.1 and 2.1.1.2, early childhood is marked by increasing volumes of play.[200,202] Amongst the BaYaka volumes of play remain relatively stable for both boys and girls between ages 5 to 10, but as individuals approach adolescence behaviours start to transition away from play and play-based learning toward productivity with this occurring earlier for girls than it does for boys.[200] In the BaYaka, girls begin to transition to productivity from ages 8 or 9, initially by taking on childcare and domestic duties, this indirectly increases productivity by releasing adults to spend more time foraging.[200,202,254] Boys transition to productivity at a later age (up to age 12), and move to direct productivity through foraging.[200] For all, productivity increases with age as individuals dedicate more time to foraging and do so with increasing efficiency.[166,206] While these transitions are gradual, as young children will forage and engage in play and learning that mirrors adult behaviours,[166,200,202] there is a progression toward the highly active adult behaviours throughout childhood and adolescence.

As such, though a decrease in physical activity during and following puberty is observed in developed market economies, such a trend may not be expected amongst hunter-gatherer youth.[201,379] For both, puberty presents the beginning of the transition to adulthood, with numerous cultures across multiple models of subsistence marking such a transition as the beginning of adulthood.[427] With this, there is also the beginning of a move towards adult behaviours, which, given the high levels of physical activity being observed in adulthood for hunter gatherers, may also involve an increase in physical activity from puberty through to full adulthood.

For the BaYaka, childhood is less marked by age-related thresholds in which their behaviour is restructured. While children change behaviour as they develop and mature, for individuals away from major settlements, there is no stepping point from which individuals notably alter their daily behaviours. This contrasts with studies in developed market economies, for which, children between age 4 and 6 will move from play-based learning to a formalised classroom structure.[379] While this transition is gradual, it does restrict children's autonomy over their activity by structuring the day around spells of sedentary behaviours. Notably, this transition correlates with a change in patterns of activity, with average activity across the life course peaking before the onset of formal schooling (See section 4.4).[379]

In post-industrial populations, a gender divide in childhood volumes of physical activity is frequently observed in the existing research (See section 1.1.3.3 and Chapter 3).[428] It remains to be seen whether similar differences would be observed in hunter-gatherer children. While BaYaka adults were observed to have minimal divisions in the volume of activity between the genders (See section 5.3.1), this may not represent stable differences at all ages. Further, gender differences amongst hunter-gatherer populations are mixed, with only 6 of 23 identified studies noting a divide 5.1.3.1. As such, it may be that between genders levels of infant and childhood physical activity may not differ, with differences only emerging as children begin to partake in more gendered activities as they transition to primary productivity.

6.1.2 BaYaka children as a model of constrained activity.

Physical activity in hunter-gatherers' can be used to develop a model of what activity looked like for most human populations before the transition to agriculture and the culmination of this cultural evolution seen in contemporary post-industrial populations.[157] Though a naturalistic fallacy should be avoided in examining physical activity patterns within the BaYaka, populations outside of the scope of traditional epidemiological literature can be used to explore truisms established in studies of physical activity in market economies.

Childhood is marked by a prolonged period of development, physically, neurologically, immunologically and sexually.[203] This is highlighted in life course studies of energy expenditure, in which basal metabolic rates are highest in childhood.[146] With the severe effects of a lack of energy availability on childhood development, a drive to not overspend energy should be highly conserved.[429,430] With activity presenting a signification fraction of total energy expenditure, BaYaka children should only engage in as much activity as they can sustain. In post-industrial populations the precarity of these trade-offs with energy and development can be seen in youth studies documenting 'Relative Energy Deficiency in Sport' (RED-S).[66] For hunter-gatherers, with raised rates of childhood mortality,[145] this balancing act is even more precarious and is amplified through seasonal variability in resource availability.[188]

6.1.3 Behaviours across a BaYaka day.

Unlike post-industrial children for whom daily patterns of activity are entrained by school timetables,[431] daily behaviours in hunter-gatherers may be more variable. In the absence of formal structuring of the day, BaYaka, children are largely free to determine their own activities.[255] As discussed in section 2.1.1.2, BaYaka children spend large portions of the day in play but will join foraging efforts including fishing, caterpillar collecting and setting traps, as well as caring for younger children and supporting family chores.[200,205] For BaYaka adults (aged 17+), Kilius et al., (2021)[432] observed daily activity to have two peaks, one in the morning and one in the evening with an active afternoon between the two points.[432] The same study observed the start and end of the waking day to be consistent between individuals, with wake-times reflecting ambient light conditions.[432] As such, there is some need to expand this to include children. With children engaging in their own activities, their patterning of activity may differ from adults. Elsewhere, it has been proposed that adolescents may also observe a shifted wakeful period, with later bedtimes and wake up times, as a hypothesised evolved chronotype to create a time to socialise away from adults, but supporting evidence centres on post-industrial populations.[433]

6.1.4 Research questions.

To address the aforementioned gaps in the literature, the present study aims to objectively quantify patterns of activity in a group of hunter-gatherer children across and within days, and examine whether variation between individuals' mirrors observed trends in post-industrial populations.

I. Do the gendered activity patterns observed in Chapter 5 arise through childhood?
II. Do volumes of physical activity increase with age in BaYaka children?
III. How do BaYaka children structure activity across their day?
IV. In all of these manners, how do patterns of activity in the BaYaka contrast to post-industrial populations?

6.2 Methodology

6.2.1 Mbendjele BaYaka.

As introduced in section 2.1.1 , the BaYaka are a group of hunter-gatherers residing in the rainforests of the Congo Basin with the Mbendjele being a subgroup defined by their use of the Mbendjele language.[250] While BaYaka children will often accompany adults as they go to the forest each day to forage, children are treated as independent decision makers with autonomy over their activity.[400] Early childhood is marked by increasing independence and large volumes of play.[200] As children approach adolescence they begin to undertake productive behaviours.[200,205] Girls transition away from play to productivity earlier than boys, initially indirectly by taking on caregiving and camp maintenance roles.[200,254] Boys transition away from play at a later age and move to direct productivity by increasing the volume of time dedicated to foraging and hunting.[166,200]

6.2.2 Sample and data collection.

Data for this analysis comes from two field trips; the first was undertaken in July and August of 2018 (and forms part of the sample in Chapter 5), with a subsequent fieldtrip undertaken between January to February 2022. Both field trips sampled from the same region within the Sangha River basin in northern Congo-Brazzaville. The two field trips occurred in differing foraging seasons, with the 2022 data collected during fishing season, with the 2018 data collected during caterpillar season. The research and fieldworks were approved by the Ethics Committee of University College London (UCL Ethics codes

3086/003), and the methods were carried out in accordance with the approved guidelines. Informed consent was obtained from all participants and research permission granted by the Republic of Congo's Ministry of Scientific Research.

As in Chapter 5, physical activity patterns were quantified using a GENEActiv accelerometer, here including all children aged between 3 and 18 years. In 2018 participants wore the device for a minimum of 24hrs, while in 2022 device were worn for seven days. In 2018 children varied in what weekday they began wearing the device. While there is variation in behaviours engaged in each day, unlike post-industrial populations, these are not structured around a particular day of the week.[434] In 2022 the recording started and finished on the same day for all participants. Data from both 2018 and 2022 are included together here as there were minimal differences in activity between the two field trips (Table S D-3).

After being collected back, accelerometer recordings were processed using the R package GGIR as outlined in 2.3.2 and employed in section 5.2.[286,288] Reflecting the study protocol, the maximum recording length was set to 7 days from the start of recording, and only including days with at least 16hrs of wear time included in analysis. While no restriction on excluding the first or last day of study was stipulated, this was included de facto by excluding all days with less than 16hrs of recording. Data was calculated in 24-hour windows from midnight to midnight, based on West Africa time (UTC +1 hour). In Chapter 5, each individuals recording was presented as one average day per person, due to the shorter recording period. With 7 days of recording in 2022, physical activity data for all individuals was collated for each individual at a daily level (1 entry per person per day of recording) for individuals in the 2018 and 2022 field visit, and an hourly level (1 entry per person per hour of each day) for individuals in the 2022 field visit. Mirroring methods employed in Chapter 5, acceleration is calculated as milligravitational units and subset into standard thresholds (Sedentary ≤ 50mg < Light ≤ 100mg < Moderate ≤ 400mg < Vigorous),[285,289] with MVPA being a sum of all the minutes in moderate or vigorous intensities.

Between the two fieldtrips, 71 children aged up to 19 years wore a GENEActiv accelerometer device on their non-dominant arm. In 2018 46 children (9 boys) wore the device for up to two consecutive days. In 2022, 24 children (12 Boys) wore the device for 5 consecutive days. Children were excluded from the present analysis if they were aged under 3 years (n=6), if their accelerometery data was corrupted during recording (n=1) or if they did not have at least one complete day (midnight-midnight) of recording (n = 13). Together this left a sample of 51 children (2018 = 28, Total Boys = 29) totalling 150 days of activity recording (Table 6-1).

Demographic data was collected alongside the physical activity data. This includes information on gender, included as a binary measure of "boy" or "girl, with all participating individuals reporting as such. As in Chapter 5, age is included as years of age where known and was reported by the individual or a family member. For those without a known age, age estimates for participants were based on a Bayesian method using relative age ranks based on those with known ages.[258]

6.2.3 Comparison populations.

Two datasets were used to contrast BaYaka children's physical activity levels with post-industrial populations. In the present study, the National Health and Nutrition Examination Survey (NHANES) was used to compare patterns of activity between the BaYaka and a post-industrial population, but due to differing methodologies could not be directly compared. Instead, to directly compare volumes of activity, data from the 6th sweep of the UK Millennium Cohort Study (MCS) was used.[261,435]

NHANES employs a metric called MIMS (Monitor Independent Motion Sensing)[436], a technique similar to HPFVM (High-Pass Filter Vector Magnitude).[437] The difference between this and mg ENMO, is that mg ENMO treats gravity as a constant, meaning 1g is subtracted from the acceleration; a HPFVM or MIMS technique does not assume gravity is constant and instead treats gravity as a low frequency component to be filtered out.[438] The millennium cohort recorded physical activity in a similar matter but processed activity using GGIR to generate activity estimates in mg ENMO.

6.2.3.1 National Health and Nutrition Examination Survey.

The NHANES sample included here contained 2391 children (1200 boys) aged between 5 and 18 years (Table S D-1). The mean age was 11 years 8 months, and was similar between boys and girls (boys: 10.60 years; girls: 10.76 years). Of the individuals included, 25% identified as non-Hispanic White, 25% and non-Hispanic Black, 25% as Mexican American, 10% as other Hispanic and 15% as Other ethnicity. The mean MIMS were 14,673 and were similar between boys and girls (boys: 14,534 MIMS; girls: 14,813 MIMS).

6.2.3.2 Millennium Cohort Study.

Activity data was collected using wrist-worn triaxial accelerometers when participants were 14 years old and includes 4,533 individuals (2,182 boys) (Table S D-2).

6.2.4 Analysis

6.2.4.1 Modelling BaYaka activity.

To account for the variable recording lengths between children, linear mixed effect models are employed to examine difference between ages and genders, using the lme4 package in R.[286,439] The mean acceleration across the day or the volume of time in a given threshold of activity was used as the outcome. Models were adjusted for age and gender, both as additive effects, and with an interaction term to allow gender specific slopes for age. Additionally, year of recording was included in the models to account for potential seasonal differences between the two visits to the field (Table S D-3). Individual ID was included as a random effect to adjust for clustering of values within an individual across the days of recording.

Mixed effect models were also used to analyse differences in activity across the day. Mean accelerations were averaged over 3-hour windows, for each day of recording for each child. The effect of time of day (in 3-hour windows) was modelled against the mean acceleration in that window, with the fixed covariates of age and gender included. To account for the nested clustering of results within days and within individuals, random effects of weekday and individual ID were included to reflect this nesting of groups. Only data collected in 2022 was used for analysis of within day variation in activity due to the reduced length of recording in 2018. As before, the reference for these models was a boy's activity, with the reference time window being in the middle of the sleep window (midnight – 3am). Three-hour windows were used to improve the contrast between windows of time and reduce the number of pairwise comparisons.

To examine the any variation between days of recording the interclass correlation (ICC) was calculated to estimate the individual variation in average acceleration across the available days of recording. The ICC is calculated from the ratio of the variance of interest (sum of squares from the mean acceleration) compared to the total variance (sum of squares + the residual). To obtain an ICC estimate for the BaYaka sample, intercept only mixed effect models were run, amongst the 2022 sample of BaYaka, for whom five days of recording were available. To contrast this value, the ICC in the NHANES sample was also calculated with 5 days of recording included to match the BaYaka sample.

6.2.4.2 Modelling patterns of activity in the BaYaka and a US sample.

To compare the BaYaka and NHANES study, the mean acceleration on each day of recording (measured as mg ENMO & MIMS Unit) was standardised using internally calculated z-scores. Z-scored mean accelerations were then employed in mixed effect linear models adjusted for age, gender and population as fixed effects, with the individual ID included as a random effect. To examine differences between populations in the slope with age, an interaction term was included between age and population.

The same process of z-score standardisation was undertaken to examine difference between populations in the distribution of activity throughout the day. As before, activity was averaged over three-hour windows. Mixed effect linear models were used to model the effect of time of day on proportional physical activity, including the study population as an interaction term for time of day, with age and gender included as covariates. Individual ID and day of the week were included as random effects. The reference time window in this model differs from the analysis of activity across the day in the BaYaka. to improve the interpretability of the output the time window of 03:00-06:00 was used as the reference as difference between populations was at a minimum during this time window.

6.3 Results

6.3.1 Physical activity in BaYaka children.

Compared to WEIRD samples, BaYaka children were exceptionally active. Across the sample of 51 children (29 boys), the average day included over three hours of MVPA (Boys: 206min/day, Girls: 192min/day), a volume triple the WHO recommendations for children (Table 6-1).[76] The average 24-hour period included a further three hours of light intensity activity, with 17 hours a day spent sedentary, over 9 hours of which was wakeful. Together, this resulted in a mean acceleration of 47 mg ENMO (Boys: 48mg; Girls: 45mg; Table 6-1). Compared to the average physical activity level of the British 14-year-olds in the UK MCS dataset, amongst the five 14-year-old BaYaka the mean acceleration was 16mg higher, with volumes of MVPA 65% greater (Figure 6-3). Across all included BaYaka children, of the 150 days of recording only 2 days of recording (one from a boy in 2018, one from a girl in 2022) did not exceed 60 minutes of MVPA.

Table 6-1: Summary Statistics presented for BaYaka boys and girls.

	Overall	Boys	Girls
n	51	29	22
Age	10.90 (4.35)	10.20 (4.60)	11.81 (3.93)
Recorded in 2022 (n, %)	23 (45.1)	12 (41.4)	11 (50.0)
Mean Acceleration (mg ENMO)	46.60 (13.23)	48.12 (15.45)	44.61 (9.55)
Sedentary (Min/Day)	1066.63 (89.69)	1071.05 (99.89)	1060.79 (76.06)
Of Which: Wakeful (Min/Day)	585.87 (129.17)	583.07 (133.14)	589.55 (126.74)
Light (Min/Day)	182.74 (38.38)	174.24 (38.69)	193.94 (35.78)
MVPA (Min/Day)	199.95 (70.94)	206.24 (75.14)	191.66 (65.79)
Of Which: Moderate (Min/Day)	179.90 (60.45)	183.45 (64.96)	175.21 (55.06)
Of Which: Vigorous (Min/Day)	19.36 (14.82)	21.64 (17.10)	16.36 (10.79)
Wake-up Time (hh:mm)	05:49 (01:05)	05:46 (01:17)	05:53 (00:52)
Sleep Onset (hh:mm)	21:46 (01:09)	21:33 (1:24)	22:01 (00:48)

Note: Reported as mean and standard deviation in brackets, to 2 significant figures.

6.3.2 Variation in BaYaka children's physical activity by age and gender.

The average acceleration increased with age across the included children, with little difference between boys and girls (Table 6-2). Both boys and girls increased by approximately 1mg for each additional year of age, maintaining a consistent trajectory between them (Figure 6-2, Table 6-2). In contrast, the children in the US NHANES sample were more active in early childhood, and their activity declined with increasing age (Figure 6-2). Using internally calculated z-scored daily accelerations, mean accelerations in the NHANES sample decreased with age by 0.11 standard deviations for each additional year of age (Table S D-5). Comparatively, the BaYaka were least active in early childhood (marked by a negative intercept), with activity increasing by 0.05 standard deviations for each additional year of age.

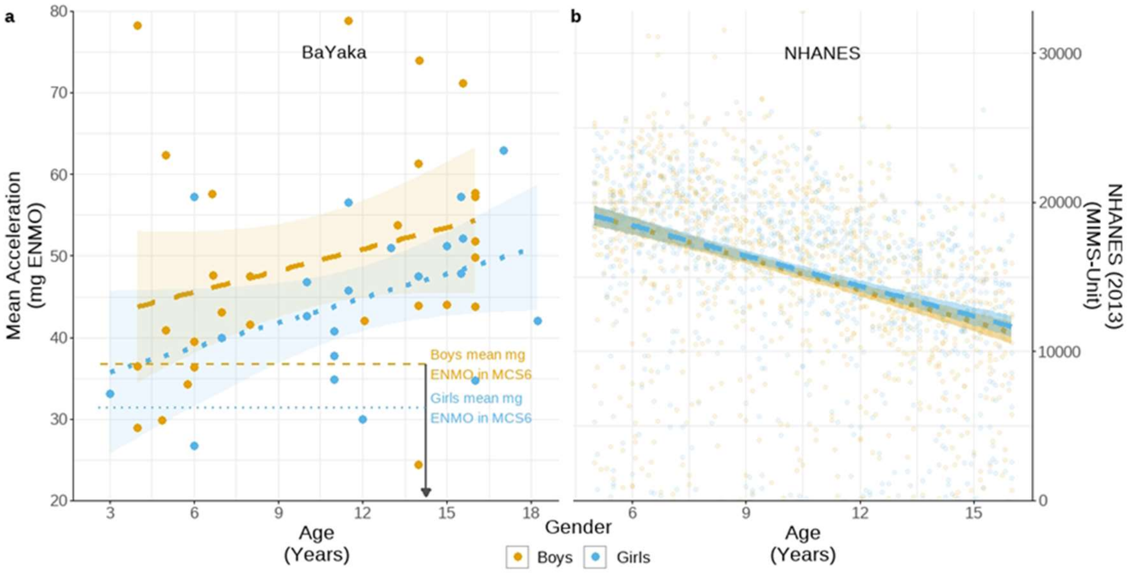


Figure 6-2: Mean acceleration amongst (a) BaYaka children as measued by mg ENMO and (b) US children in the 2013 NHANES study measured in MIMS-Unit. For both samples, all individuals aged between 3 and 18 years are included. Horizontal dashed (boys) and dotted (girls) in panel a represent mean volumes observed in the Millennium Cohort Study (MCS6) where individuals were 14 years old. The Millennium Cohort Study processed physical activity in a manner consistent to that employed here, facilitating direct comparison among the 14-year-olds. Note that it is not possible to make direct comparisons of volumes of activity with the NHANES data due to the difference in the measurement unit.

Separating overall activity in the BaYaka into the standard activity thresholds, the increase in mean acceleration was driven by greater volumes of moderate to vigorous intensity activities which in turn were offset by a decrease in sedentary activity (Figure 6-3). Volumes of MVPA was similar for both boys and girls, increasing by 8 minutes per day for each additional year of age. Offsetting this, volumes of sedentary behaviour decreased by an estimated 10 minutes per day for each additional year of age (Table 6-2), with no meaningful difference between boys and girls. Of this, volumes of wakeful sedentary behaviour appear to be stable with increasing age, (for each additional year: -5mins) indicating that any differences in sedentary activity with age were also driven by changes in the sleep phase; the time between sleep onset and wake-up. As with sedentary behaviours, there were minimal changes to the estimated volumes of light intensity activity with age (for each additional year: +2mins).

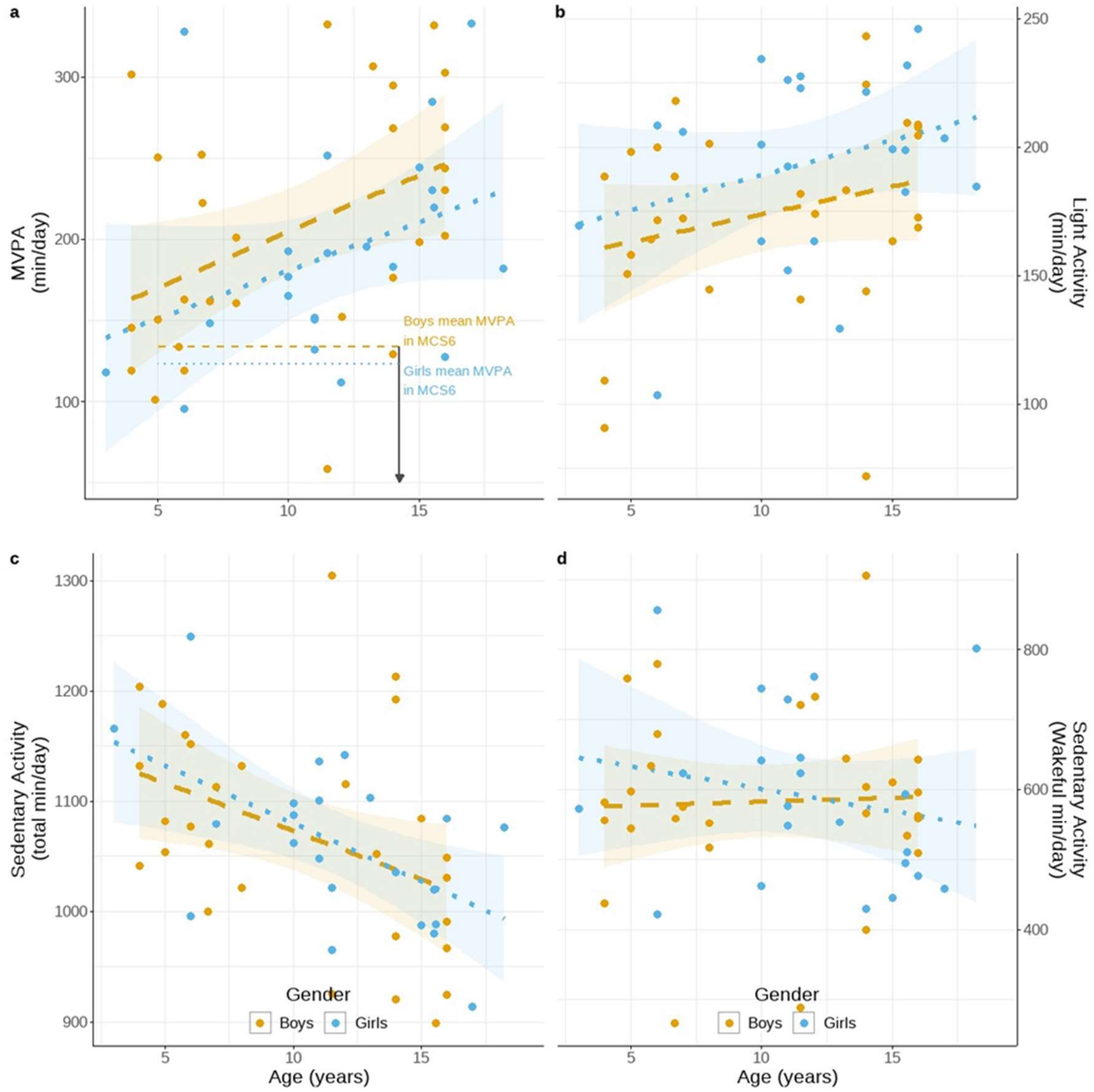


Figure 6-3: Mean volumes of activity per day by age. Boys are shown in yellow and girls in blue (a) volume of moderate-to-vigorous intensity physical activity (mg ENMO > 100 mg) (b) volume of light intensity activity (mg ENMO: 50-99 mg), (c) volume of sedentary activity including sleep (mg ENMO < 50 mg), (d) volume of wakeful sedentary activity (mg ENMO < 50 mg). In panel a, the horizontal dashed (boys) and dotted (girls) represent mean volumes observed in the Millennium Cohort Study (MCS6) where individuals were 14 years old. The Millennium Cohort Study processed physical activity in a manner consistent to that employed here, facilitating direct comparison. Only values for MVPA and mg ENMO have been made available from MCS6. The volume of MVPA here includes all minutes above the threshold of 100 mg ENMO.

Table 6-2: Linear mixed effect model coefficients for mean acceleration and each activity intensity examining the effect of age and gender as fixed effects with and without an interaction term.

	Mean Acceleration		**MVPA**		**Light Activity**		**Sedentary Activity**		**Of Which: Wakeful**	
Predictors	*Additive*	*Interaction*	*Additive*	*Interaction*	*Additive*	*Interaction*	*Additive*	*Interaction*	*Additive*	*Interaction*
(Intercept)	**37.3 ***** **(27.4 – 47.2)**	**37.7 ***** **(25.9 – 49.5)**	**119.5 ***** **(72.2 – 166.9)**	**125.3 ***** **(69.1 – 181.5)**	**146.2 ***** **(116.8 – 175.6)**	**148.3 ***** **(113.3 – 183.3)**	**1167.9 ***** **(1104.9 – 1230.9)**	**1163.5 ***** **(1088.6 – 1238.4)**	**647.7 ***** **(546.2 – 749.3)**	**601.9 ***** **(486.4 – 717.4)**
Age	**0.9 *** **(0.1 – 1.6)**	**0.8** **(-0.1 – 1.8)**	**7.9 ***** **(4.2 – 11.7)**	**7.4 **** **(2.8 – 12.0)**	**2.5 *** **(0.2 – 4.8)**	2.3 (-0.6 – 5.2)	**-9.9 ***** **(-14.8 – -5.0)**	**-9.5 **** **(-15.7 – -3.4)**	-5.4 (-13.4 – 2.7)	-1.2 (-10.8 – 8.3)
Gender [Girl]	-4.5 (-11.1 – 2.1)	-5.6 (-25.4 – 14.1)	-24.1 (-56.1 – 8.0)	-41.2 (-136.7 – 54.2)	14.3 (-5.5 – 34.1)	8.1 (-50.6 – 66.7)	7.6 (-34.8 – 49.9)	20.5 (-105.9 – 146.8)	30 (-39.0 – 99.0)	176 (-23.3 – 375.4)
Year [2018]	4.6 (-2.0 – 11.1)	4.5 (-2.1 – 11.2)	9.5 (-23.0 – 42.0)	8.9 (-23.8 – 41.7)	5.5 (-14.1 – 25.0)	5.3 (-14.6 – 25.1)	-6.7 (-48.7 – 35.4)	-6.3 (-48.8 – 36.3)	-27 (-99.5 – 45.5)	-21.8 (-92.9 – 49.3)
Age × Gender [Girl]		0.3 (-1.3 – 1.9)		2.2 (-6.1 – 10.4)		2.5 (-2.3 – 7.3)		-4.9 (-15.4 – 5.6)		-15.4 (-32.8 – 2.0)
					Random Effects					
σ^2	82.13	82.03	3231.56	3247.39	699.95	699.82	4090.25	4094.81	21763.38	22115.31
τ_{00}	95.31 ID	98.64 ID	1685.27 ID	1704.61 ID	847.31 ID	872.91 ID	3577.49 ID	3677.25 ID	5575.15 ID	4579.81 ID
ICC	0.54	0.55	0.34	0.34	0.55	0.56	0.47	0.47	0.2	0.17
N	51 ID	51 ID	51 ID	51 ID	51 ID	51 ID	51 ID	51 ID	51 ID	51 ID
Observations	150	150	147	147	145	145	148	148	145	145
Marginal/ Conditional R^2	0.099 / 0.583	0.097 / 0.590	0.193 / 0.469	0.192 / 0.470	0.108 / 0.597	0.107 / 0.603	0.186 / 0.566	0.183 / 0.570	0.027 / 0.225	0.050 / 0.213

Note: All complete days were included for all individuals. Reference was a Boy aged 0, recorded in 2022. Values are estimate and 95% confidence interval. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

6.3.3 Diurnal activity patterns.

Daily activity was diurnally patterned in BaYaka children (Figure 6-4). Morning light appears to mark the start of the waking day, but sunset did not mark the end of the waking day, with activity extending into the late evening. Throughout the night (21:00 to 06:00) children were at their least active but transitioned into their most active window in the late morning (09:00 to 12:00: 80mg: Table 6-3). Throughout the afternoon (12:00 to 18:00) children remained relatively active, with the mean intensity plateauing at approximately 65mg. The first and final wakeful windows (06:00 to 09:00 & 18:00 to 21:00) were less active at approximately 40mg each, as individuals transitioned out of or into the sleep period.

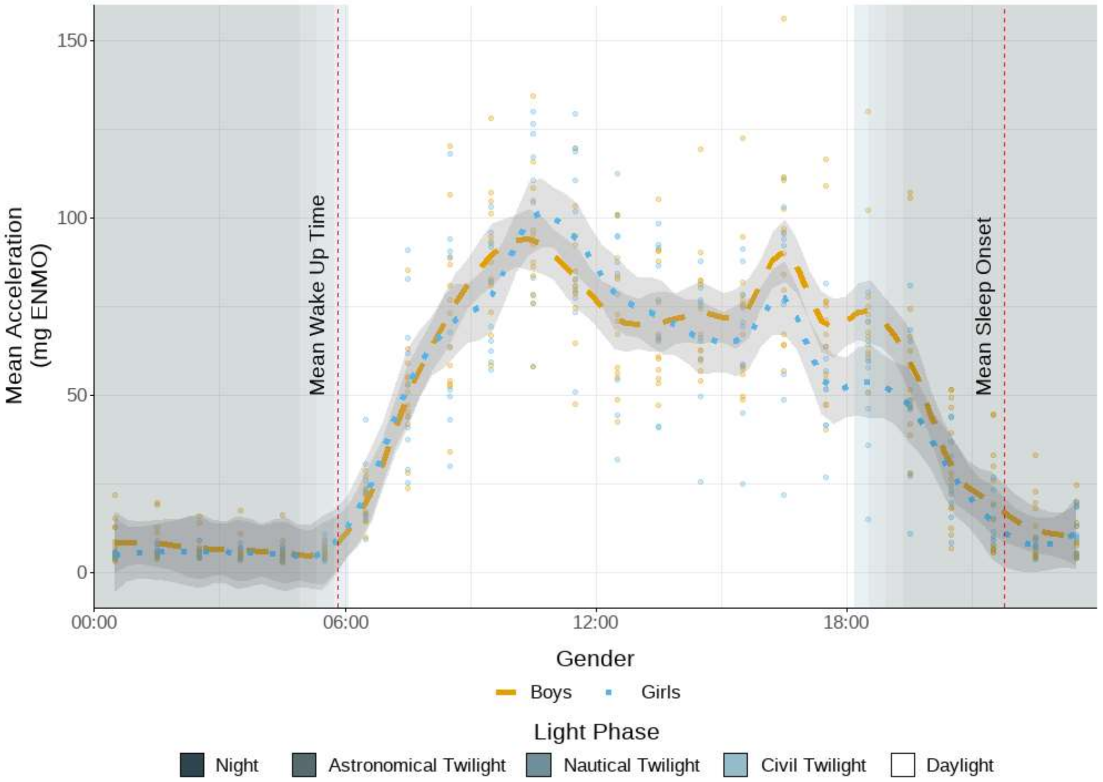


Figure 6-4: Distribution of physical activity throughout the day. For each individual in the 2022 data collection, their mean acceleration at each hour averaged across the 5 days of recording is presented as a single point, with colour corresponding to gender. The mean acceleration was calculated for each hour interval and presented at the half hour (i.e. the mean acceleration between 09:00 and 10:00 is presented at 09:30). Presented light phases were taken from the nearest settlement on the first day of recording. Sunrise in Pokola on 13/2/22 was at 06:06, with morning twilight beginning at 05:45. Mean wake-up time in this sample was 05:49 with the average onset of sleep at 21:46 as detected by the device. Sleep was calculated as the single largest block of time for which the device moves less than 5º in any axis over a 5 second epoch, averaged over a 10minute window, allowing for a break of sleep for up to 1 hour.[290]

Volumes of MVPA were distributed across the day in a similar manner to the overall acceleration (Include in SI Table S D-4). Children spent the greatest proportion of time in MVPA through the late morning (09:00 to 12:00), spending approximately 20 minutes of each hour in MVPA. The afternoon (12:00 to 18:00) included less time in MVPA, with an estimated volume of 13 minutes each hour spent in MVPA. Of the wakeful time windows, the early morning and late evening contained the least MVPA (06:00 to 09:00 & 18:00 to 21:00), with approximately 8 minutes of each hour spent in MVPA.

Table 6-3: Linear mixed effect model coefficients for the mean acceleration at each three-hour interval of time.

	Mean Acceleration (mg ENMO)
Predictors	***Estimates***
(Intercept)	-5.47 (-16.85 – 5.91)
03:00 – 06:00	-1.14 (-6.37 – 4.08)
06:00 – 09:00	41.17 *** (35.94 – 46.39)
09:00 – 12:00	83.30 *** (78.07 – 88.52)
12:00 – 15:00	65.30 *** (60.08 – 70.52)
15:00 – 18:00	65.53 *** (60.31 – 70.76)
18:00 - 21:00	42.56 *** (37.34 – 47.78)
21:00 – 24:00	5.73 * (0.51 – 10.95)
Age	1.31 ** (0.37 – 2.24)
Gender [Girl]	-4.52 (-11.71 – 2.67)
Random Effects	
σ^2	407.30
τ_{00} (weekday:device_sn)	20.37
τ_{00} (device_sn)	59.59
ICC	0.16
N_{weekday}	5
$N_{\text{device\_sn}}$	23
Observations	920
Marginal R^2 / Conditional R^2	0.667 / 0.722

Note: The effect of age and gender are included as fixed effects with the day of recording nested within each individual as a random effect. All complete days were included for all individuals. Reference is a Boy aged 0. Values are estimate and 95% confidence interval. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

6.3.4 Changes in activity may be driven by older children staying up later.

There was little variation in when individuals transitioned out of sleep, with more variation in individuals time of sleep onset. In Figure 6-4, all individuals moved away from the overnight baseline in a one-hour interval being at the base line between 05:00 and 06:00 but moving away from it by 06:00 to 07:00. However, in the evening there was greater variation in the times at which individuals returned to the over-night baseline. By age, there was no evidence for variation in when individuals woke, but older children entered the sleep an estimated 10 minutes later per year of age. This increase with age may act to offset some of the decrease in sedentary activity previously observed.

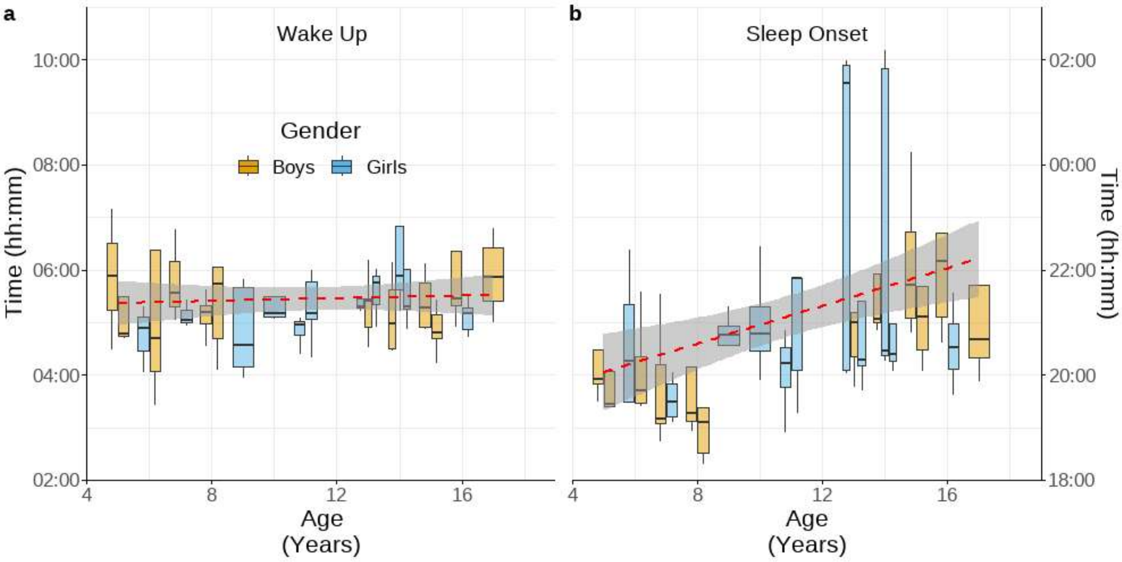


Figure 6-5: Device estimated (a) wake up and (b) sleep onset times across individuals. Dashed red line represents the estimate from linear model. Y-axes are matched in length to 9 hours each to aid interpretation. Sleep is classified by GGIR as any block of 10 minutes, in which the average movement of the device is less than 5o in any axis over each 5 second epoch. The algorithm defines the longest sustained inactive bout within each day as sleep, allowing for the sleep bout to be disrupted for up to one hour before. From this the estimated onset and end of sleep windows can be calculated as the final and first timepoint in each day in which an individual was not in a device defined bout of sleep

Table 6-4: Mixed effect model estimates of wake up and sleep onset times.

Predictors	**Wake Up Time** ***Estimates***	**Sleep Onset** ***Estimates***
(Intercept)	05:00 *** (03:18 – 06:49)	19:43 *** (17:58 – 21:27)
Age	00:04 (-00:05 – 00:13)	00:10 * (00:02 – 0:19)
Gender [Girl]	00:05 (-01:05 – 01:14)	00:23 (-00:44 – 01:29)
Random Effects		
σ^2	9.79	8.96
τ_{00} **(Individual ID)**	0.00 device_sn	0.00 device_sn
N	23 device_sn	23 device_sn
Observations	115	115
Marginal R^2 / Conditional R^2	0.008 / NA	0.51 NA

Note: Estimates are presented as hh:mm. Intercepts represent a time of day, with effects showing a deviation in hours and minutes. The effect of age and gender are included as fixed effects with the day of recording nested within each individual as a random effect. All complete days were included for all individuals from the 2022 data collection. Reference is a Boy aged 0. Values are estimate and 95% confidence interval. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

6.3.5 BaYaka days differ to American Days

Compared to the NHANES sample, the BaYaka rose to their peak activity levels early in the morning, maintained a high resting level of activity through the middle of the day, observed a slight rise at around 17:00, before declining across the evening into the sleep window. The NHANES sample appears to transition more slowly into their active behaviours with activity plateauing from midday through to 20:00, with a slight peak in the evening, before declining into the night. The plot implies that the BaYaka are mostly inactive (i.e. asleep) by midnight, but a proportion of the NHANES sample is still reporting active behaviours, thus awake at this time.

In the both the BaYaka and NHANES samples have their activity levels begin to rise at similar times in the morning, with the start of the inflection off the x-axis beginning between 05:00 and 06:00. From this the BaYaka observe a steeper gradient in rising activity levels to a peak in mid-morning. The first of two possible explanations for this steeper gradient could be that the BaYaka rapidly transition from the sleep period (where activity should be lowest) to their most active period of the day. The second is that BaYaka are more constrained in their wakeup time, thus the steeper gradient is driven by all individuals transitioning from inactivity to activity (at any level) over a shorter window of time, with the NHANES sample less constrained in their wakeup time, having more variation in this window with a mixture of individuals being either awake (and active) or asleep (inactive).

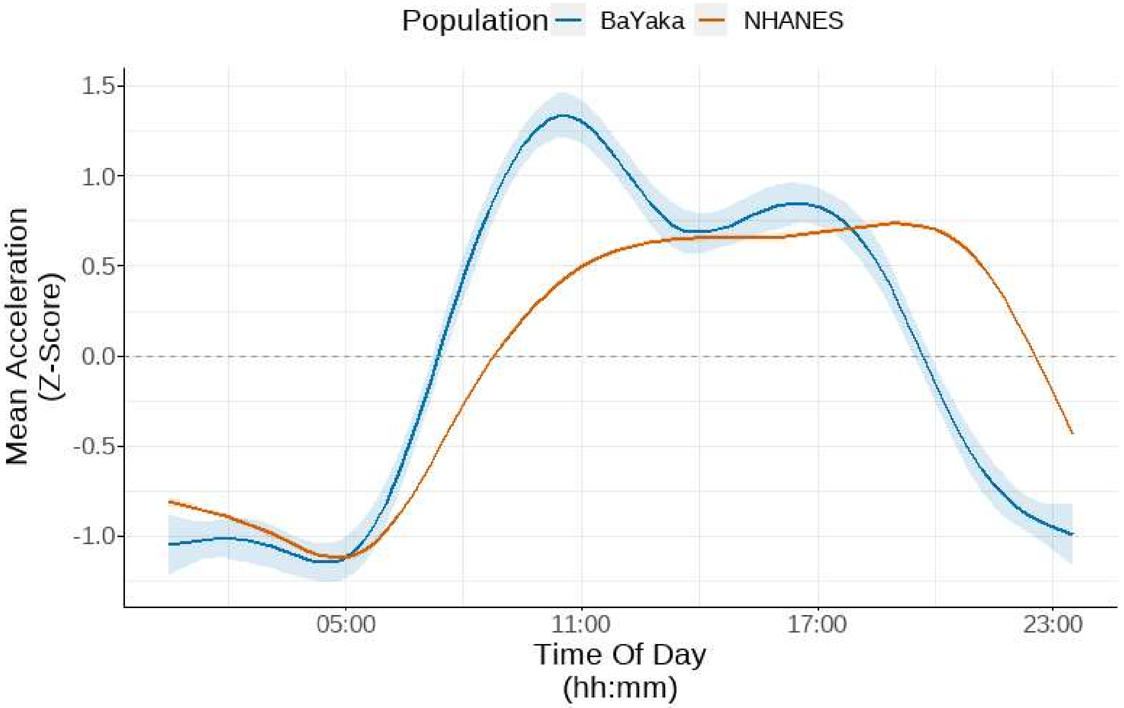


Figure 6-6: Distribution of physical activity throughout the day in the BaYaka and NHANES datasets. Measures of acceleration are standardised within each sample.

Grouping activity into three hour windows, the BaYaka are engaging in more of their daily activity during daylight hours (between 06:00 and 18:00), with the largest positive differential for BaYaka during the morning (06:00 to 12:00) (Table 6-5). NHANES had a positive differential, in the evening and night (between 18:00 and 24:00), indicating that individuals in NHANES undertook a larger proportion of their activity in the evening. During the sleep window (00:00 to 06:00) there were minimal differences between the two samples.

Table 6-5: Abridged mixed effect model of standardised mean accelerations in three hour windows across the day in the BaYaka and NHANES sample.

	Mean Acceleration (Z-Score)
Predictors	*Estimates*
(Intercept)	-0.51 *** (-0.70 – -0.32)
NHANES : 0-3am	0.02 (-0.14 – 0.19)
NHANES: 3-6am	0.11 (-0.07 – 0.30)
NHANES : 7-9am	**-0.35** *** **(-0.52 – -0.18)**
NHANES : 10-12am	**-0.83** *** **(-1.00 – -0.66)**
NHANES : 13-15pm	-0.16 (-0.33 – 0.01)
NHANES : 16-18pm	-0.12 (-0.29 – 0.05)
NHANES : 19-21pm	**0.37** *** **(0.20 – 0.54)**
NHANES : 22-24pm	**0.44** *** **(0.27 – 0.61)**
Random Effects	
σ^2	0.42
τ_{00} weekday:id	0.03
τ_{00} id	0.11
ICC	0.25
N weekday	12
N id	2483
Observations	135925
Marginal R^2 / Conditional R^2	0.579

***Note: Full model output available in Table S D-6. The effect of age and gender are included as fixed effects with the day of recording nested within each individual as a random effect. All complete days were included for all individuals. Reference is the standardised acceleration of a BaYaka child between 3am and 6am. Values are estimate and 95% confidence interval. **** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

6.3.6 Activity amongst BaYaka children varies between days.

Compared to US children in the NHANES dataset, BaYaka children exhibited more variation in how much activity they undertook each day. Using intercept only mixed effect models on standardised mean accelerations amongst BaYaka children with five days of recording (N=23) to match the length of recording in NHANES, a lower intra-class correlation (ICC) (0.50) was observed for BaYaka children than US children (0.66) (Table 6-6). ICC measures variability within a group (here an individual's ID) between 0 and 1. An ICC of 1 would indicate that all entries are equal to the individuals mean, with lower scores indicating greater variability. Thus, BaYaka observing a lower ICC implies greater variation between days of recording.

Table 6-6: Intercept only mixed effect models of Z-Scores physical activity in the BaYaka and NHANES sample.

	BaYaka (Z-Scored Mean Acceleration) *Estimates (CI)*	**NHANES (Z-Scored Mean Acceleration)** *Estimates (CI)*
(Intercept)	-0.00 (-0.32 – 0.32)	0.07 *** (0.04 – 0.10)
	Random Effects	
σ^2	0.51	0.33
τ_{00}	0.51 $_{\text{ID}}$	0.64 $_{\text{ID}}$
ICC	0.50	0.66
N	23 $_{\text{ID}}$	2721 $_{\text{ID}}$
Observations	115	14301
Marginal R^2 / Conditional R^2	0.000 / 0.497	0.000 / 0.657

Note: Each individual ID is included as a random effect. All complete days were included for all individuals from the 2022 data collection in the BaYaka and the 2013 NHANES sample. Values are estimate and 95% confidence interval. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

6.4 Discussion

6.4.1 Summary of results

For BaYaka children the average day included over three times the WHO recommended volumes of daily MVPA, with only two days of recording (of 150) across all individuals failing to exceed 60 minutes.[76] Compared to British adolescents in the MCS, BaYaka children engaged in over an hour more MVPA per day (211 vs 128 min/day) resulting in a mean acceleration 15mg higher. If the BaYaka sample is restricted to those aged 14 or older, the difference increased to an additional two hours of MVPA and 20mg for the BaYaka.

Unlike observations in MCS, no difference between boys and girls in the BaYaka was observed. Additionally, volumes of activity increased with age, rather than decreased as seen in NHANES and other post-industrial nations.[428] For each additional year of age, BaYaka children spent an additional 11 minutes a day in MVPA, which appears to be offset by time spent sedentary, which reduced by 13 minutes for each additional year of age. This exchange of time in thresholds underlies the increase in daily average acceleration of 1mg for each additional year; this volume previously been put forward as the minimum clinically important difference in daily average acceleration for inactive adults, equating to an approximate increase of 5 minutes of MVPA amongst adults.[440]

Across the day there is sizable variation in patterns of activity. BaYaka children observe a diurnal pattern of activity, with the primary sleep window occurring between 22:00 and 06:00. Children were at their most active in the late morning but remained active throughout the afternoon. BaYaka children largely wake up together at a time that appears to reflect ambient natural light, with the average wake-up occurring just before sunrise. Sleep onset was more variable, while there was no variation between boys and girls, older children observed a later onset of sleep. In addition to variation within the day, there was sizable variation between days. Compared to US children in the NHANES dataset (ICC = 0.66), BaYaka children exhibited more variation in how much activity they undertook each day (ICC = 0.50). This may a reduced structure to children's daily lives amongst BaYaka, allowing more autonomy over daily activity volumes.

6.4.2 Contextualising activity patterns

Observational research can be used to add behavioural context to the trends in activity recorded in the present study. For hunter-gatherer children, daily activity is characterised by large amounts of time spent in play, while the form of play varies with age, the overall volume increases until late childhood (age 5-9) and plateaus as the dominate daily behaviour until early adolescence.[200,202]

As children approach adolescence play is incrementally replaced with behaviours that help provide calories, either directly through foraging, or indirectly by allowing others to spend more time foraginh.[205] The timing of this transition varies between individuals, with girls often starting this transition in time allocation earlier, though initially indirectly. [200] This stepwise increase in play followed by productivity could explain the trajectory of activity with age, as individuals increase the proportion of the day spent active through early and middle childhood, then increase the intensity of activity through adolescence.

Absent from the results is a difference in activity levels between boys and girls despite gender stereotyped behaviours. While boys and girls will spend equally large volumes of time in mixed-gender play groups, there is variation in the type of play boys and girls spend their time in.[202] Children preferably model in play gender-stereotyped adult behaviours, with girls spending more time playing house, compared to boys spending more time play hunting.[202] The division in behaviour develops as children transition away from play, with girls doing so at an earlier age, initially into domestic work and childcare, before increasing the volume of time spent foraging, with boys retaining a large volume of play for longer before transitioning to foraging in adolescence, with a focus on hunting.[200,205] The present study therefore expands a view of egalitarianism in the BaYaka from an equitable division of labour amongst adults, into a fair division of activity that begins early in the life course despite differing behaviours.[190] This results contrasts with observations in post-industrial populations, amongst whom there is a pervasive gender divide in activity levels, which appears at a young age and remains throughout most of the life course.[7,8,111,112,120,293–297]

The observed variation in daily activity patterns reflects a distribution of activity throughout the day. Akin to Kilius et al.'s (2021) study,[432] the BaYaka children included here followed a clear diurnal pattern. There are two peaks in the distribution, one in the mid to late morning and one in the late afternoon, both of which coincide with large bouts of walking (Figure 6-4). In the morning as children move from their overnight camp into the forest for the day, and in the afternoon before sunset as children return to the overnight camp before sunset falls on the forest. While children remained active in the afternoon, the average intensity was lower, as was the fraction of time spent in MVPA, likely due to the behaviours being more intermittently active than the blocks of walking. The first and final waking blocks of the day contained low levels of activity, reflecting a transition out of or into the sedentary sleep window.

In addition to variation in waking behaviours, the BaYaka children also varied in their sleep patterns. While sleep onset did not appear to be structured around natural light cycles, older children observed a later sleep onset. Conversely, no stratified variation in wake-up times by age was observed, with all children waking at approximately the same time. Mirroring results amongst Hadza adults in occurring just before sunrise, the wake-up times appear to be entrained by ambient light conditions.[397] The observed sleep patterns amongst the BaYaka support observations from post-industrial populations that older children require less sleep, but do not support a view of adolescents having an evolved universal chronotype with a delayed sleep onset and wake-up time.[433,441,442]

6.4.3 BaYaka insights into modern mismatches

Two cultural phenomena help highlight the cross-cultural differences and social drivers of differing activity trajectories between BaYaka and post-industrial children, those of formalised schooling and the transition to adolescence.[201] In post-industrial populations at ages 5 or 6 learning starts to move from being play-based to a formal sedentary classroom setting, reducing the time available to be active. This shift restricts individual autonomy in activity. This transition in post-industrial populations results in the majority of childhood activity occurring in the few hours after school, though as seen in Chapter 3, this may be driven by a subset of the population.[443,444] For the BaYaka, in the absence of prescribed daily behaviours, children have more freedom to pick their activities and at no timepoint is there a shift that encourages sedentary behaviour. Further highlighting this is the increased variability between days seen in the BaYaka compared to NHANES (Table 6-6). Weekdays for the children in NHANES follow a similar structure around school schedules, but BaYaka children have more autonomy in varying their activity between days.

For both BaYaka and post-industrial children adolescence marks the beginning of the transition toward adulthood, yet this results in contrasting trajectories of activity (Figure 6-2). A core difference is in the behaviours they are increasingly modelling with age; for hunter-gatherer's the archetypal adult is highly active, but post-industrial parents are often less active than their children.[87,445] The role of active post-industrial adults is seen in their children frequently observing higher levels of activity than their peers.[371,446] To ensure any improvement in childhood activity is not squandered as soon as adolescents leave school, adult inactivity also needs to be addressed.

Further complicating the role of behavioural role models, is the gender divide in physical activity in post-industrial populations[7,8,111,112,120,293–297] proposed to be a result of gender stereotyped behaviours.[331] With the BaYaka able to exhibit gendered behaviours,[200] without a difference in activity levels, the issue may not be that children are engaging in different behaviours but that 'stereotypical' behaviours are disproportionately inactive for girls. Incorporating this perspective may involve creating more spaces and opportunities for girls to be active with other girls without engaging in behaviours stereotyped as 'for boys'.[331]

6.4.4 Strengths

To our knowledge this is the first study to objectively quantify physical activity patterns in hunter-gatherer children across the full 24hr window for multiple days. In doing so, this research provides not only summary levels of activity in an understudied population, but examines how activity varies between individuals. Extending from this, the pattern of activity within the day is also assessed. Finally, rather than using summary measures, direct comparisons to activity levels in post-industrial populations are made, comparing to both the US NHANES and British MCS datasets. Together, the BaYaka children included here provide a counterpoint to increasingly sedentary post-industrial childhoods and places post-industrial ecologies as central to understanding of the burgeoning physical inactivity crisis.

6.4.5 Limitations

As discussed in Chapter 5, sample size is a constraint in most studies of small-scale societies, which may mean that there is less power to detect smaller differences between individuals. Notably, a gender differences amongst BaYaka children may be obscured due to sample sizes, as in the MCS sample absolute differences in activity appear to be smaller, but do meet statistical significance. Despite smaller sample sizes, the number of children included here exceeds the number of individuals of all ages included in some previous studies of hunter-gatherers (Table S C-1). Compared to these studies and given the observed variability between days, using multiple complete days of recording strengthens the argument that even if activity measures are not representative of all BaYaka children, they are representative of the included children.

Amongst studies of the BaYaka, interpretations of sleep onset and wake-up are determined by the device and draws from when the device changes from a sustained period of inactivity (further detail in 2.4) to being more frequently in motion (an example of the device output during this transition is available in Figure S D-3). As such, without additional observational data, it is not possible to separate whether individuals are going to sleep or just remaining inactive. As such, focus in this chapter is placed on the waking day rather than sleep, as either interpretation does not diminish observed differences in the beginning and end of the active day.

In contrasting activity across the day between the BaYaka and NHANES, it was not possible to compare differences in sleep onset and wake up, due to the interpretation of the day length in NHANES being limited due to variable recording periods. While all individuals in NHANES were standardised to their own time zone, information on when in the year data was collected restricts an ability to infer light periods.

6.4.6 Concluding remarks and links to other chapters

BaYaka children engaged in three time the WHO recommend volumes of activity that many post-industrial children fail to meet, and notably exceeded volumes of activity undertaken by British adolescents.[76] Further adding to this cross-cultural contrast is the increasing volumes of activity with age, that were comparable for boys and girls, unlike observations in Chapter 3 and the MCS sample here. The increase in activity with age was driven by increased time in MVPA, exchanged with time in sedentary intensities. This clearly contrasted to those in the NHANES, with standardised activity proportionally increasing amongst the BaYaka by as much as it decreased amongst American youth. Underlying this was a reduction in the time spent in bed, with older children observing later sleep onsets.

This chapter adds nuance to the transitions in activity with age seen in Chapter 5, focussing on the transition from precocial infants to active young adults. Though centred on adults, for a wider discussion on activity patterns in BaYaka hunter-gatherers, please see Chapter 5. Together these highlight the activity patterns of BaYaka adults, and how they develop throughout childhood. Similar methods examining differences in activity levels between genders can be seen in Chapter 3 and differences between post-industrial countries is available in Chapter 4. While the difference between nations is noted there, the scale of difference between Americans and the BaYaka notably exceeds those included in Chapter 4. The value of studying subsistence populations to understand the relationship between physical activity patterns and health are discussed in section 1.2. A wider discussion on the role of physical activity is included in section 1.1. This chapter employs accelerometery which differs to some hunter-gatherer studies included in Table S C-1, a discussion on how differing methods of objective physical activity measurement may lead to differing outcomes are discussed in section 2.1

Chapter 7 Conclusions and general discussion

This thesis has aimed to fill in some of the missing diversity in physical activity research, focussing on children's activity through the ICAD and BaYaka samples. The first core theme was to broaden an understanding of how activity within a population is conceptualised beyond an analysis of the mean. Working with the BaYaka, the second theme was to explore how physical activity is distributed amongst a subsistence population outside of traditional epidemiological literature. This focussed both on examining the social determinants of activity within the BaYaka and testing how this differed from post-industrial populations. This concluding Chapter reviews the key findings from the thesis and situates their broader implications into the wider realm of physical activity research and health. The relative strengths and limitations of the overall thesis are discussed, which may help inform the future research that could be conducted.

7.1 Summary of main findings

Physical activity markedly differed between the social and cultural groups included in this thesis. In particular, this thesis has demonstrated a gulf in activity between high income countries and hunter-gatherer populations, which may go some way to explain the NCD health gap between these two populations.[157] Notably, this thesis adds evidence outlining the differences in children's activity between hunter-gatherer and high income populations, revealing a large deficit in activity amongst US and UK youth that only grows with age. Amongst these post-industrial youth, differences in activity between boys and girls appears to be largely socio-cultural, as amongst the BaYaka, for whom being active is neither 'for boys' or 'for girls',[331] no difference in activity was observed. While a child's gender was strongly associated with the distribution of MVPA in the ICAD dataset, the country in which the child was from had a larger effect than gender on the amount of light intensity activity they undertook. Akin to a hunting and gathering lifestyle requiring large amounts of activity, populations that embed more habitual, light intensity activity into their children's daily lives had higher overall volumes of activity.

In studying the ICAD dataset with a GAMLSS approach, marked differences in the distribution of individuals may help explain differences in the mean between groups. Addressing the first aim of the thesis, while boys were more active on average, there was more variation between boys. As such, differences in the mean were driven by a sizeable subset undertaking notably more activity than girls, rather than all boys doing a small amount more. No difference was observed in the distribution of light activity between boys and girls, supporting a view that children share baseline levels of activity which is augmented by a greater proportion of boys undertaking large volumes of MVPA, as found in sports and active play. Turning to the second core aim of the thesis, While gender did not have a meaningful effect at light intensities of activity, nation of study did. Broadly, those that were more active for one measure of activity were active in all measures, and those that were more variable in one measure were more variable in all measures. Where light intensity activity was lowest, variation was highest, possibly reflecting that in populations where policies, infrastructure and attitudes that encourage habitual activity, such as active travel to school, are less uniform across the population, so too is physical activity.

Addressing the third and fourth aims of the thesis, both chapters on the BaYaka reveal a highly active population, where adults and children regularly undertook over three hours of MVPA per day. Amongst the BaYaka, physical activity appeared to increase with age across childhood, peak in early adulthood, before slowly declining after the age of 50. Unlike high income countries, gender differences in activity did not appear in childhood, but seemed to be present in early adulthood, which may reflect a division in labour as this could not be explained by the overt maternal factors of gestation or lactation. For children, while their activity was structured by the day, with wake-up entrained by sunrise and a daily pattern centred around movement into and out of the forest, activity was not structured across days, with more variability between days than US children. Being more active with age appears to be partially resultant from later bedtimes, which contrasts with US youth who also have later adolescent bedtimes, but a notable decrease in activity with age.

7.2 Potential implications

In working with the ICAD dataset, the importance of considering the full distribution of activity levels were emphasized. A GAMLSS approach highlighted that many individuals were failing to meet recommended volumes of activity, which was partially hidden by mean volumes inflated by an active subset at the upper tail of the distribution. Between boys and girls, this emphasises the potential role of leisure-time activity in differentiating the average boy and girl, despite the increased inequality in activity amongst boys. With the BaYaka, this thesis also highlights that this ‘consistent’ observation is a likely product of socio-cultural differences rather than biology. High volumes of activity across the life course were similarly observed for BaYaka boys and girls, and men and women, reflecting the egalitarian division of labour in this population.

Better understanding the full distribution of activity levels in a population may aid strategies for intervention design . For example, findings from this thesis suggest that where interventions aim to tackle the average disparity between boys and girls, creating more opportunities for girls to partake in leisure-time MVPA may be an effective approach. However, this thesis also highlights that decreasing the disparity in MVPA between boys and girls may also act to increase the inequality amongst girls. Instead, where there is an interest in shifting the entire populations distribution, targetting light intensity ‘lifestyle’ activity may provide more equitable outcomes. While there is almost certainly benefit in both increasing the opportunity to partake in leisure time MVPA as well as integrating more lifestyle activity into the daily lives of children, altering the environment may have a more ubiquitous effect on overall activity than attempting to alter the motivation to partake in MVPA.[243,447] Given the non-linear relationship between physical activity and health,[2] both targeted approaches which target the least active and population-wise approaches which have larger effects amongst the least active may have the most benefit to population health .[239–242]

Applying this to address gendered inequality in activity during childhood may have implications for inequalities in health across the life course. With the girls included in the present research more likely to be lowly active, this may increase their risk for non-communicable disease outcomes.[15] Women do appear to have a higher risk of obesity and arthritis[123] (though the later may be augmented by age-related declines in estrogen production), for which low levels of activity in childhood and across the life course may contribute.[113] With the added association between childhood and adult activity levels[58], tackling inequality in activity early may be an effective avenue of intervention. However, it should be noted that more evidence from a wider array of sources is needed to causally link gendered differences in distributions of activity during childhood to differing distributions of health outcomes across the life course.[448]

National policy and attitudes to activity can have meaningful impacts on the equality of activity between children. The USA invests heavily into youth sport,[359] but has made little investment into active infrastructure, including facilitating walking and cycling.[104,359] This may partially underlie the generally low levels of activity observed and the increased inequality. Differentiation in activity levels is then driven by access, support and motivation to seek out opportunities to be active through sports or active play.[363–365] Conversely, in nations that embed activity into everyday life like in Switzerland, where over 70% of children engage in active transport every day,[449,450] or where the mode of subsistence requires activity like the BaYaka, children were more equally active.

Hunter-gatherers were highly active across the life course, with children and young adults regularly engaging in over three hours of MVPA per day. With hunter-gatherers proposed to embody an evolutionary equilibrium of engaging in enough activity to survive but not so much as to compromise future abilities to be active, such volumes could represent a sustainable upper limit on activity, which is notably in excess of the 400 minutes per week noted elsewhere.[69] Physical activity research often focusses on the extremes of activity; either the lowly active population samples for most of whom increasing volumes of activity is associated with beneficial health outcomes, or the highly active sportspersons who are trying to find the upper limit of sustainable activity. Hunter-gatherers and other subsistence populations may help to elucidate the highly active plateau between these two points.

Supporting an argument that ancestral hunter-gatherer groups would have undertaken high volumes of activity is the similarity in activity levels between BaYaka and other globally dispersed hunter-gather groups.[157,224] With the disparity in activity between contemporary hunter-gatherers and high income nations mirrored in the disparity in the rates of non-communicable disease (Table 1-1),[25] the radical sedenterisation of daily life amongst recent generations of post-industrial populations may have a large part to play.[25] As such, future attention should not just be paid to why high-income nations differ in their activity from each other, but why all these nations differ from an ancestral suite of behaviours.[247] For the BaYaka and other hunter-gatherer groups, being physically active is a part of daily life, with their fitness and survival dependent on it. Akin to early epidemiological research conducted by Morris et al., (1953) with postal workers and bus drivers and conductors,[451] embedding more activity into the daily lives of sedentary populations may bring meaningful improvements to overall health.

While the differing NCD burden between hunter-gatherers and high-income nations (Table 1-1) could be viewed as the benefits of an active lifestyle amongst hunter-gatherer populations, it may be better framed as a mismatch between sedentary contemporary lives and bodies shaped by ancestrally active ecologies. The BaYaka included in this thesis and other studies of hunter-gatherer activity (see Table S C-1) highlight that an ancestral lifestyle would likely have been active throughout the entire life course. The BaYaka further highlight that this mismatch is present across the life course. While low activity in later adulthood compared to elderly BaYaka may have a greater contribution to adult NCD related mortality,[58,59] the research amongst BaYaka children highlights that this mismatch begins during an individual's early developmental years, affecting how a body matures and develops, which may contribute to conditions including osteoporosis.[34]

In addition to the broader mismatch amongst high-income nations, with a non-linear relationship between activity and health and almost all BaYaka being highly active, hunter-gatherers may experience less disparity in activity related health outcomes. With only one adult (of 96) failing to meet the WHO target of 30 minutes per day in Chapter 5, and one child (out of 51) failing to exceed 60 minutes per day on average in Chapter 6. The greater inequality in activity observed amongst the broadly inactive populations included in Chapters 3 and 4 highlight that not only is the overall risk of NCDs higher, but it is also less uniformly distributed amongst the population. As such, addressing this mismatch in activity throughout the life course may act to both reduce the disparity between high-income populations and contemporary hunter-gatherers, but also reduce the health disparity within high-income populations.

The influence of activity being embedded in daily life is highlighted amongst BaYaka children. With a mode of subsistence that requires daily activity, children engaged in over three times the WHO recommended volumes. While the implication is not that these volumes of activity should be mirrored in post-industrial populations, instead it should prompt a reflection on how to encourage more activity amongst children. Notably, approaches to schooling should also be considered when assessing childhood activity. While activity decreased with age following the onset of formal schooling in the ICAD and other studies,[8,379] the BaYaka only became more active with age. Further highlighting this is the increased variability between days observed in the BaYaka. Where school fosters a consistent but low level of activity, in the absence of schooling BaYaka children are free to self-determine their activity. Developing the curriculum to facilitate more active learning may help to bring about improvements from the bottom up.[452] Where interventions have attempted to break up these large blocks of sedentary activity in children, volumes of light and moderate to vigorous intensity physical activity have increased.[443] Schooling is however only part of the problem as activity is typically higher on school days than it is on weekends.[434]

7.3 Strengths and Limitations

7.3.1 Strengths

Using a breadth of studies and methodologies, this thesis has expanded upon existing cross-national studies of physical activity to explore differences in the distribution across socio-cultural groups. With physical activity research often centred on high-income nations, this research has looked to expand this by providing a high-quality reference point for physical activity amongst a hunter-gatherer population, and in particular a reference for hunter-gatherer children. With the ICAD dataset, this thesis expands upon existing research documenting gender and population differences in activity to understand how the full distribution of activity across all intensities can expand our understanding of the drivers of activity inequality. Though this is not the first piece of research to look at the distribution of physical activity in a population (see Chaput et al., (2018) using GINI coefficients,[348] and Bann et al., (2019) discussion on the PISA dataset using self-reported data)[116], no other identified literature has employed GAMLSS to examine the full distribution of objectively measured accelerometry. With the BaYaka, this research has looked to apply methods typical of epidemiology to an anthropological research area. In doing so, this has provided a detailed account of daily activity patterns amongst an understudied rainforest population, with direct comparisons with post-industrial populations.

Although some limitations to the selected datasets are detailed below, overall, the individuals and studies included are a strength of this study. The ICAD is the largest harmonised dataset of children accelerometry to date, here including 15,461 children across 9 countries in adjusted models. While the contributing studies vary in their degree of representativeness, the ICAD allows for the direct comparison of globally distributed children that would not otherwise be possible. Sample sizes amongst the BaYaka are small compared to the epidemiological datasets included in this thesis but this reflects the constraints of collecting data amongst scale-scale societies; for instance, amongst the Hadza, as of 2002 there were less than 400 people still practicing a foraging mode of subsistence.[453] Though the BaYaka are more numerous, they are widely distributed throughout the Congo rainforest, with camps typically only containing 10 to 60 individuals. [400] Without the funding of epidemiological studies in high-income nations, and with hunter-gatherers rapidly transitioning away from an immediate return model of subsistence,[188,189] these accounts provide a valuable reference point amongst a rapidly changing population. A sample of 126 individuals in Chapter 5 makes it one of the largest accounts of objective physical activity in a hunter-gatherer population (Figure 5-2) and Chapter 6's 51 children is the largest identified sample of objectively measured activity amongst hunter-gatherer children to date.

7.3.2 Limitations

The limitations to each piece of research is detailed in the respective chapters, but there are some general limitations to the broad conclusions outlined here. Firstly, this thesis has used cross-sectional data throughout. While differences between individuals have been examined, there is little ability to compare profiles of activity within an individual. As such, when examining time variant variables like age, cohort effects are introduced. For instance, amongst BaYaka children it is not possible to disentangle whether they become more active with age, or whether the older cohort have always been more active. With a relatively stable ecology it is assumed that there are little meaningful generational differences in activity, but repeated longitudinal measures would be needed to confirm this. Equal assumptions are made with the ICAD and NHANES datasets. While the spread of ages is narrower in these studies due to only containing children, being cross-sectional, the risk of generational effects is present.

The BaYaka samples also contend with small sample sizes. This could influence the power of analyses and restrict the wider generalisability of the conclusions from this population. With reduced power to detect smaller differences, larger sample size might help to elucidate the marginal differences observed, such as those between BaYaka women in section 5.3.3. A reduced sample size could allow observed effects to be more greatly influenced by outliers, but no notable individuals were observed when examining the data. Small samples could also restrict the generalisability to the wider BaYaka population. While a limitation, small sample sizes are often a constraint in anthropological research, with the sample size here being comparable to, or larger than other pieces of hunter-gatherer research. Simply, it is not presently possible to undertake studies of a similar scale to NHANES or MCS amongst a hunter-gatherer population. Instead, this thesis sought to apply a similar level of methodological rigour to a small-scale population. Adding plausibility to a view that the observed volumes of activity likely reflect the true population levels of activity, is that the results broadly are similar to those observed in other hunter-gatherer studies (as discussed in section 5.4).

For the research involving the ICAD dataset, the GAMLSS methodology required complete cases to work, which would likely have lowered the power of analysis and may have introduced bias due to missing individuals. While this led to the exclusion of 3,519 individuals from the adjusted models, the results in the minimally adjusted model were comparable when employing either the restricted or unrestricted sample. The primary missingness was driven by parental education (a binary measure of whether parents had received education beyond state minimums) which did not appear to alter any of the estimates.

This thesis analyses the output of accelerometers, both waist and wrist-worn. As discussed in section 2.2.2.1, there are some general limitations to their use. Generally, the devices are good at measuring movement, but are limited in their ability to measure load. For instance, two children walking together, but only one carrying a heavy rucksack, would have similar accelerometer outputs despite differing weights being carried. Amongst the BaYaka this could have led to their activity being incorrectly estimated if weight bearing activity is socially patterned between groups. As discussed in Chapter 5, this could contribute to the reduction in activity amongst older BaYaka adults. Accelerometers may also underrepresent activity accumulated through cycling.[273] In nations that have a high uptake of cycling as a form of active commuting, such as the Danish EYHS study in ICAD, their overall activity may be underestimated. Future research could seek to employ modes of dual sensing, such as using combined heart rate and accelerometer sensors.

Finally, ICAD, MCS and NHANES are secondary datasets, removing control over the methods employed in data collection and processing. While all of these studies attempt to capture the same latent concept, differences in study design influenced the ability to directly compare between studies in this thesis. A such, where processing decisions were made by the author, they were made to aid the comparison with available and comparable datasets. With the 2018 BaYaka data conceived and collected prior to the involvement of this author, processing decisions were made to maximise the comparability of this data to existing research. Here the choice of device best suited comparisons with the UK Millennium Cohort which in turn mirrors the UK Biobank methodology.[263,415] Accordingly, the 2022 data collection used the same device and processing method to ensure that the BaYaka children's data was directly comparable to data collected in 2018.

7.4 Future directions

A pervasive problem in physical activity research, including this research, is breadth of studied populations.[454] Exemplified in the included ICAD study, only one study was conducted in a non-European or English speaking nation (Brazil). This limits the nuance in comparing across nations as populations are culturally similar and potentially non-independent due to a shared history.[245,247] At present, global south populations are chronically understudied, and this plays true in both physical activity and broader epidemiological research.[94,454] Further, establishing whether there is a difference between countries, leads to questions as to why there is a difference between countries, which with the limited representativeness and available data is difficult to answer meaningfully with the ICAD dataset. Equally, the GAMLSS methodology applied here showed that differences between groups is often driven by the disparity within groups. Future research could also seek to examine how the distribution and variation of groups differs in addition to the mean.

Amongst hunter-gatherers, for the reasons outlined previously, it is a challenge to obtain large sample sizes. Instead, a focus should be placed on collecting more data from different subsistence groups, including other BaYaka, Aka and Baka who despite geographical proximity experience different ecological pressures.[250] From this, an understanding of what ecological factors may underlie differing activity patterns can be developed, as well as a developed understanding of what an overarching interpretation of 'hunter-gatherer' fitness looks like. Within this, there is a particular dearth of information on the activity profiles of children, and a lack of direct comparability between studies.

Within Chapter 6, differences between individuals of varying ages are used to infer what changes would happen within an individual. To more accurately document individual changes requires repeated measures of an individual across their life course. While some projects are set up to repeat data collection within a particular group (such as the Tsimane Health Project),[455] more concerted effort to track individuals over time would be beneficial. Particularly with the change in the mode of subsistence most hunter-gatherers are experiencing, [188] keeping a record of individuals through this transition may be key to staying ahead of any potential detrimental health outcomes.

The research conducted here is observational, and while a hunter-gatherer level of activity is proposed to underlie some of the effect on their low rates of NCDs, interventional or control trials could add detail here. Sports-based interventions and RCTs are well established means to assess the association of activity and health outcomes. However, BaYaka activity is predominantly of light and moderate intensity. Therefore, to understand the health effects of this mode of activity, studies should look to explore the long-term effects of light and moderate intensity interventions, such as targeting walking.

Finally, focus of prior research has often been placed on individual behaviours rather than the full spectrum of activity. Going forward, research should attempt to highlight the overall volumes of activity (such as mean accelerations) in addition to any thresholds. With time being finite, for an individual to spend more time in one threshold, time must be reduced somewhere else. Understanding these isotemporal substitutions is important but is particularly lacking in hunter-gatherer studies.

7.5 Concluding remarks

This thesis not only underscores the significance of comprehending cross-cultural variations in determinants of health but also illuminates the pivotal role that highly active hunter-gatherer societies play in offering a crucial counterpoint to modern sedentary cultures. Notably, while almost all contributing studies in the ICAD dataset display a consistent difference in activity between boys and girls, no such distinction is evident amongst BaYaka children. Moreover, hunter-gatherer and ICAD children displayed contrasting trends in activity levels with age: in high-income populations, activity tended to decrease with age, while in the BaYaka population, it showed an upward trajectory through childhood into adulthood.

Furthermore, this research emphasises the value of examining the full distribution of activity, beyond measures of the mean. Amongst the ICAD studies, populations that observe lower inequality in one facet of activity, such as light intensity activities, are likely to observe similar variation in others. A GAMLSS approach also demonstrated that differences between boys and girls were not driven by all boys undertaking more activity, but a sizeable subset increasing both the average and the variation in overall activity. Overall, this thesis has highlighted the importance of developing a broader understanding of the ecological determinants of physical activity both between and within cultures.

References

1. Warburton, D. E. R., & Bredin, S. S. D. (2017). Health benefits of physical activity: A systematic review of current systematic reviews. *Current Opinion in Cardiology*, *32*(5), 541–556.
2. Ekelund, U., Tarp, J., Steene-Johannessen, J., Hansen, B. H., Jefferis, B., Fagerland, M. W., Whincup, P., Diaz, K. M., Hooker, S. P., Chernofsky, A., Larson, M. G., Spartano, N., Vasan, R. S., Dohrn, I. M., Hagströmer, M., Edwardson, C., Yates, T., Shiroma, E., Anderssen, S. A., & Lee, I. M. (2019). Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: Systematic review and harmonised meta-analysis. *The BMJ*, *366*.
3. Abbafati, C., Machado, D. B., Cislaghi, B., Salman, O. M., Karanikolos, M., McKee, M., Abbas, K. M., Brady, O. J., Larson, H. J., Trias-Llimós, S., Cummins, S., Langan, S. M., Sartorius, B., Hafiz, A., Jenabi, E., Mohammad Gholi Mezerji, N., Borzouei, S., Azarian, G., Khazaei, S., … Zhu, C. (2020). Five insights from the Global Burden of Disease Study 2019. *The Lancet*, *396*(10258), 1135–1159.
4. Abbafati, C., Machado, D. B., Cislaghi, B., Salman, O. M., Karanikolos, M., McKee, M., Abbas, K. M., Brady, O. J., Larson, H. J., Trias-Llimós, S., Cummins, S., Langan, S. M., Sartorius, B., Hafiz, A., Jenabi, E., Mohammad Gholi Mezerji, N., Borzouei, S., Azarian, G., Khazaei, S., … Zhu, C. (2020). Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet*, *396*(10258), 1223–1249.
5. World Health Organisation. (2022). *Global status report on physical activity 2022*. https://www.who.int/publications-detail-redirect/9789240059153
6. World Health Organisation. (2019). *WHO guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age*. WHO.

7. Cooper, A. R., Goodman, A., Page, A. S., Sherar, L. B., Esliger, D. W., van Sluijs, E. M. F., Andersen, L. B., Anderssen, S., Cardon, G., Davey, R., Froberg, K., Hallal, P., Janz, K. F., Kordas, K., Kreimler, S., Pate, R. R., Puder, J. J., Reilly, J. J., Salmon, J., … Ekelund, U. (2015). Objectively measured physical activity and sedentary time in youth: The International children's accelerometry database (ICAD). *International Journal of Behavioral Nutrition and Physical Activity*, *12*(1), 1–10.

8. Steene-Johannessen, J., Hansen, B. H., Dalene, K. E., Kolle, E., Northstone, K., Møller, N. C., Grøntved, A., Wedderkopp, N., Kriemler, S., Page, A. S., Puder, J. J., Reilly, J. J., Sardinha, L. B., Van Sluijs, E. M. F., Andersen, L. B., Van Der Ploeg, H., Ahrens, W., Flexeder, C., Standl, M., … Van Sluijs, E. M. F. (2020). Variations in accelerometry measured physical activity and sedentary time across Europe-harmonized analyses of 47,497 children and adolescents. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 1–14.

9. Rhodes, R. E., Janssen, I., Bredin, S. S. D., Warburton, D. E. R., & Bauman, A. (2017). Physical activity: Health impact, prevalence, correlates and interventions. *Psychology & Health*, *32*(8), 942–975.

10. Sallis, R. E. (2009). Exercise is medicine and physicians need to prescribe it! *British Journal of Sports Medicine*, *43*(1), 3–4.

11. Tipton, C. M. (2014). The history of "Exercise Is Medicine" in ancient civilizations. *Advances in Physiology Education*, *38*(2), 109–117.

12. Dalene, K. E., Tarp, J., Selmer, R. M., Ariansen, I. K. H., Nystad, W., Coenen, P., Anderssen, S. A., Steene-Johannessen, J., & Ekelund, U. (2021). Occupational physical activity and longevity in working men and women in Norway: a prospective cohort study. *The Lancet Public Health*, *0*(0).

13. Janssen, I., & Ross, R. (2012). Vigorous intensity physical activity is related to the metabolic syndrome independent of the physical activity dose. *International Journal of Epidemiology*, *41*(4), 1132–1140.

14. Kang, J., & Ratamess, N. (2014). Which Comes First? Resistance Before Aerobic Exercise or Vice Versa? *ACSM's Health & Fitness Journal*, *18*(1), 9.

15. Eijsvogels, T. M. H., & Thompson, P. D. (2015). Exercise Is Medicine: At Any Dose? *JAMA*, *314*(18), 1915–1916.

16. Green, D. J., & Smith, K. J. (2018). Effects of Exercise on Vascular Function, Structure, and Health in Humans. *Cold Spring Harbor Perspectives in Medicine*, *8*(4).

17. Tjønna, A. E., Leinan, I. M., Bartnes, A. T., Jenssen, B. M., Gibala, M. J., Winett, R. A., & Wisløff, U. (2013). Low- and High-Volume of Intensive Endurance Training Significantly Improves Maximal Oxygen Uptake after 10-Weeks of Training in Healthy Men. *PLoS ONE*, *8*(5), e65382.

18. Saxena, S., Ommeren, M. V., Tang, K. C., & Armstrong, T. P. (2009). Mental health benefits of physical activity. *Http://Dx.Doi.Org/10.1080/09638230500270776*, *14*(5), 445–451.

19. Kredlow, M. A., Capozzoli, M. C., Hearon, B. A., Calkins, A. W., & Otto, M. W. (2015). The effects of physical activity on sleep: a meta-analytic review. *Journal of Behavioral Medicine 2015 38:3*, *38*(3), 427–449.

20. Sallis, R., Young, D. R., Tartof, S. Y., Sallis, J. F., Sall, J., Li, Q., Smith, G. N., & Cohen, D. A. (2021). Physical inactivity is associated with a higher risk for severe COVID-19 outcomes: a study in 48 440 adult patients. *British Journal of Sports Medicine*, *0*, 1–8.

21. Ozemek, C., Lavie, C. J., & Rognmo, Ø. (2019). Global physical activity levels - Need for intervention. *Progress in Cardiovascular Diseases*, *62*(2), 102–107.

22. Shoham, D. A., Dugas, L. R., Bovet, P., Forrester, T. E., Lambert, E. V., Plange-Rhule, J., Schoeller, D. A., Brage, S., Ekelund, U., Durazo-Arvizu, R. A., Cooper, R. S., & Luke, A. (2015). Association of car ownership and physical activity across the spectrum of human development: Modeling the Epidemiologic Transition Study (METS). *BMC Public Health*, *15*(1), 173.

23. Brownson, R. C., Boehmer, T. K., & Luke, D. A. (2005). Declining rates of physical activity in the United States: what are the contributors? *Annual Review of Public Health*, *26*, 421–443.

24. Lieberman, D. E. (2015). Is Exercise Really Medicine? An Evolutionary Perspective. *Current Sports Medicine Reports*, *14*(4), 313–319.

25. Gurven, M. D., & Lieberman, D. E. (2020). *WEIRD bodies: mismatch, medicine and missing diversity*.

26. Nesse, R. M., & Stearns, S. C. (2008). The great opportunity: Evolutionary applications to medicine and public health. *Evolutionary Applications ISSN*, *1*, 28–48.

27. Chakravarthy, M. V., & Booth, F. W. (2004). Eating, exercise, and “thrifty” genotypes: connecting the dots toward an evolutionary understanding of modern chronic diseases. *Journal of Applied Physiology*, *96*(1), 3–10.

28. Manus, M. B. (2018). Evolutionary mismatch. *Evolution, Medicine, and Public Health*, *2018*(1), 190–191.

29. Janssen, I., & LeBlanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity*, *7*(1), 1–16.

30. Daniels, J. T., Yarbrough, R. A., & Foster, C. (1978). Changes in VO2 max and running performance with training. *European Journal of Applied Physiology and Occupational Physiology*, *39*(4), 249–254.

31. Warburton, D. E. R., Haykowsky, M. J., Quinney, H. A., Blackmore, D., Teo, K. K., Taylor, D. A., McGavock, J., & Humen, D. P. (2004). Blood volume expansion and cardiorespiratory function: effects of training modality. *Medicine and Science in Sports and Exercise*, *36*(6), 991–1000.

32. Ausili, E., Rigante, D., Salvaggio, E., Focarelli, B., Rendeli, C., Ansuini, V., Paolucci, V., Triarico, S., Martini, L., & Caradonna, P. (2012). Determinants of bone mineral density, bone mineral content, and body composition in a cohort of healthy children: influence of sex, age, puberty, and physical activity. *RHEUMATOLOGY INTERNATIONAL*, *32*(9), 2737–2743.

33. Carter, M. I., & Hinton, P. S. (2014). Physical activity and bone health. *Missouri Medicine*, *111*(1), 59–64.

34. Bass, S., Pearce, G., Bradney, M., Hendrich, E., Delmas, P. D., Harding, A., & Seeman, E. (1998). Exercise Before Puberty May Confer Residual Benefits in Bone Density in Adulthood: Studies in Active Prepubertal and Retired Female Gymnasts. *Journal of Bone and Mineral Research*, *13*(3), 500–507.

35. Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *CMAJ : Canadian Medical Association Journal*, *174*(6), 801–809.

36. Barnett, L. M., Lai, S. K., Veldman, S. L. C., Hardy, L. L., Cliff, D. P., Morgan, P. J., Zask, A., Lubans, D. R., Shultz, S. P., Ridgers, N. D., Rush, E., Brown, H. L., & Okely, A. D. (2016). Correlates of Gross Motor Competence in Children and Adolescents: A Systematic Review and Meta-Analysis. *Sports Medicine*, *46*(11), 1663–1688.

37. Thomas, E., Battaglia, G., Patti, A., Brusa, J., Leonardi, V., Palma, A., & Bellafiore, M. (2019). Physical activity programs for balance and fall prevention in elderly. *Medicine*, *98*(27), e16218.

38. Batty, D., & Thune, I. (2000). Does physical activity prevent cancer? *BMJ : British Medical Journal*, *321*(7274), 1424–1425.

39. Colberg, S. R., Sigal, R. J., Fernhall, B., Regensteiner, J. G., Blissmer, B. J., Rubin, R. R., Chasan-Taber, L., Albright, A. L., & Braun, B. (2010). Exercise and Type 2 Diabetes. *Diabetes Care*, *33*(12), e147–e167.

40. Furman, D., Campisi, J., Verdin, E., Carrera-Bastos, P., Targ, S., Franceschi, C., Ferrucci, L., Gilroy, D. W., Fasano, A., Miller, G. W., Miller, A. H., Mantovani, A., Weyand, C. M., Barzilai, N., Goronzy, J. J., Rando, T. A., Effros, R. B., Lucia, A., Kleinstreuer, N., & Slavich, G. M. (2019). Chronic inflammation in the etiology of disease across the life span. *Nature Medicine*, *25*(12), 1822–1832.

41. Thomas, N. E., & Williams, D. R. R. (2008). Inflammatory factors, physical activity, and physical fitness in young people. *Scandinavian Journal of Medicine & Science in Sports*, *18*(5), 543–556.

42. Burini, R. C., Anderson, E., Durstine, J. L., & Carson, J. A. (2020). Inflammation, Physical Activity, and Chronic Disease: An Evolutionary Perspective. *Sports Medicine and Health Science*.

43. Scarmeas, N., Luchsinger, J. A., Schupf, N., Brickman, A. M., Cosentino, S., Tang, M. X., & Stern, Y. (2009). Physical activity, diet, and risk of Alzheimer disease. *JAMA - Journal of the American Medical Association*, *302*(6), 627–637.

44. Ahlskog, J. E., Geda, Y. E., Graff-Radford, N. R., & Petersen, R. C. (2011). Physical Exercise as a Preventive or Disease-Modifying Treatment of Dementia and Brain Aging. *Mayo Clinic Proceedings*, *86*(9), 876–884.

45. Smith, P. J., & Merwin, R. M. (2021). The Role of Exercise in Management of Mental Health Disorders: An Integrative Review. *Annual Review of Medicine*, *72*, 45–62.

46. Toenders, Y. J., Laskaris, L., Davey, C. G., Berk, M., Milaneschi, Y., Lamers, F., Penninx, B. W. J. H., & Schmaal, L. (2022). Inflammation and depression in

young people: a systematic review and proposed inflammatory pathways. *Molecular Psychiatry*, *27*(1), 315–327.

47. Stevens, M., Lieschke, J., Cruwys, T., Cárdenas, D., Platow, M. J., & Reynolds, K. J. (2021). Better together: How group-based physical activity protects against depression. *Social Science & Medicine*, *286*, 114337.
48. Timmons, B. W. (2016). Exercise and Immune Function in Children: *Http://Dx.Doi.Org/10.1177/1559827606294851*, *1*(1), 59–66.
49. Cieslak, T. J., Frost, G., & Klentrou, P. (2003). Effects of physical activity, body fat, and salivary cortisol on mucosal immunity in children. *Journal of Applied Physiology*, *95*(6), 2315–2320.
50. Owen, C. G., Nightingale, C. M., Rudnicka, A. R., Sattar, N., Cook, D. G., Ekelund, U., & Whincup, P. H. (2010). Physical activity, obesity and cardiometabolic risk factors in 9- to 10-year-old UK children of white European, South Asian and black African-Caribbean origin: The Child Heart and health Study in England (CHASE). *Diabetologia*, *53*(8), 1620–1630.
51. Platat, C., Wagner, A., Klumpp, T., Schweitzer, B., & Simon, C. (2006). Relationships of physical activity with metabolic syndrome features and low-grade inflammation in adolescents. *Diabetologia*, *49*(9), 2078–2085.
52. Ruiz, J. R., Ortega, F. B., Warnberg, J., & Sjöström, M. (2007). Associations of low-grade inflammation with physical activity, fitness and fatness in prepubertal children; The European Youth Heart Study. *International Journal of Obesity*, *31*(10), 1545–1551.
53. Poitras, V. J., Gray, C. E., Borghese, M. M., Carson, V., Chaput, J. P., Janssen, I., Katzmarzyk, P. T., Pate, R. R., Connor Gorber, S., Kho, M. E., Sampson, M., & Tremblay, M. S. (2016). Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged

children and youth. *Applied Physiology, Nutrition and Metabolism*, *41*(6), S197–S239.

54. García-Hermoso, A., Ezzatvar, Y., Ramírez-Vélez, R., Olloquequi, J., & Izquierdo, M. (2020). Is device-measured vigorous-intensity physical activity associated with health-related outcomes in children and adolescents? A systematic review and meta-analysis. *Journal of Sport and Health Science*.
55. Biddle, S. J. H., & Asare, M. (2011). Physical activity and mental health in children and adolescents: A review of reviews. *British Journal of Sports Medicine*, *45*(11), 886–895.
56. Veldman, S. L. C., Chin A Paw, M. J. M., & Altenburg, T. M. (2021). Physical activity and prospective associations with indicators of health and development in children aged <5 years: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *18*(1), 1–11.
57. Gunter, K. B., Almstedt, H. C., & Janz, K. F. (2012). Physical activity in childhood may be the key to optimizing lifespan skeletal health. *Exercise and Sport Sciences Reviews*, *40*(1), 13–21.
58. Hallal, P. C., Victora, C. G., Azevedo, M. R., & Wells, J. C. K. (2006). Adolescent physical activity and health: A systematic review. *Sports Medicine*, *36*(12), 1019–1030.
59. Malina, R. M. (2001). Physical Activity and Fitness: Pathways From Childhood to Adulthood. *J. Hum. Biol*, *13*, 162–172.
60. Brechot, M., Nüesch, S., & Franck, E. (2017). Does sports activity improve health? Representative evidence using local density of sports facilities as an instrument. *Applied Economics*, *49*(48), 4871–4884.

61. Batty, G. D. (2002). Physical activity and coronary heart disease in older adults: A systematic review of epidemiological studies. *European Journal of Public Health*, *12*(3), 171–176.

62. Strain, T., Wijndaele, K., Sharp, S. J., Dempsey, P. C., Wareham, N., & Brage, S. (2020). Impact of follow-up time and analytical approaches to account for reverse causality on the association between physical activity and health outcomes in UK Biobank. *International Journal of Epidemiology*, *49*(1), 162–172.

63. Kujala, U. M. (2018). Is physical activity a cause of longevity? It is not as straightforward as some would believe. A critical analysis. *British Journal of Sports Medicine*, *52*(14), 914–918.

64. Blair, S. N., Jacobs, D. R., & Powell, K. E. (1985). Relationships between exercise or physical activity and other health behaviors. *Public Health Reports*, *100*(2), 172–180.

65. Jones-Palm, D. D. H., & Palm, J. (2005). *Physical Activity And Its Impact On Health Behavior Among Youth*. International Council of Sport Science and Physical Education.

66. Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., Meyer, N., Sherman, R., Steffen, K., Budgett, R., & Ljungqvist, A. (2014). The IOC consensus statement: Beyond the Female Athlete Triad-Relative Energy Deficiency in Sport (RED-S). *British Journal of Sports Medicine*, *48*(7), 491–497.

67. Batty, G. D., Frank, P., Kujala, U. M., Sarna, S. J., Valencia-Hernández, C. A., & Kaprio, J. (2023). Dementia in former amateur and professional contact sports participants: population-based cohort study, systematic review, and meta-analysis. *eClinicalMedicine*, *61*.

68. Boreham, C., & Riddoch, C. (2001). The physical activity, fitness and health of children. *Journal of Sports Sciences*, *19*(12), 915–929.

69. Eijsvogels, T. M. H., Thompson, P. D., & Franklin, B. A. (2018). The 'Extreme Exercise Hypothesis' Recent Findings and Cardiovascular Health Implications. *Current Treatment Options in Cardiovascular Medicine*, *20*(10), 84.

70. Dahabreh, I. J., & Paulus, J. K. (2011). Association of Episodic Physical and Sexual Activity With Triggering of Acute Cardiac Events: Systematic Review and Meta-analysis. *JAMA*, *305*(12), 1225–1233.

71. Kapczuk, K. (2017). Elite athletes and pubertal delay. *MINERVA PEDIATRICA*, *69*(5), 415–426.

72. Malina, R. M., Rogol, A. D., Cumming, S. P., e Silva, M. J., & Figueiredo, A. J. (2015). Biological maturation of youth athletes: assessment and implications. *BRITISH JOURNAL OF SPORTS MEDICINE*, *49*(13), 852–859.

73. Antero, J., Tanaka, H., De Larochelambert, Q., Pohar-Perme, M., & Toussaint, J.-F. (2021). Female and male US Olympic athletes live 5 years longer than their general population counterparts: a study of 8124 former US Olympians. *British Journal of Sports Medicine*, *55*(4), 206–212.

74. Lawrence, D. W. (2017). Sociodemographic profile of an Olympic team. *Public Health*, *148*, 149–158.

75. Pontzer, H. (2018). Energy Constraint as a Novel Mechanism Linking Exercise and Health. *Physiology*, *33*(6), 384–393.

76. World Health Organization. (2020). *WHO Guidelines On Physical Activity And Sedentary Behaviour*.

77. Public Health England. (2016). *Health matters: getting every adult active every day*. https://www.gov.uk/government/publications/health-matters-getting-every-adult-active-every-day/health-matters-getting-every-adult-active-every-day

78. World Health Organisation. (2010). *Global Recommendations on Physical Activity for Health*. WHO.

79. Pontzer, H., Raichlen, D. A., Wood, B. M., Mabulla, A. Z. P., Racette, S. B., & Marlowe, F. W. (2012). Hunter-Gatherer Energetics and Human Obesity. *PLoS ONE*, *7*(7), e40503.

80. Swift, D. L., Johannsen, N. M., Lavie, C. J., Earnest, C. P., & Church, T. S. (2014). The role of exercise and physical activity in weight loss and maintenance. *Progress in Cardiovascular Diseases*, *56*(4), 441–447.

81. Pontzer, H. (2022). Exercise is essential for health but a poor tool for weight loss: a reply to Allison and colleagues. *International Journal of Obesity*, 1–2.

82. Westerterp, K. R. (2013). Physical activity and physical activity induced energy expenditure in humans: measurement, determinants, and effects. *Frontiers in Physiology*, *4*, 90.

83. Skrede, T., Aadland, E., Anderssen, S. A., Resaland, G. K., & Ekelund, U. (2021). Bi-directional prospective associations between sedentary time, physical activity and adiposity in 10-year old Norwegian children. *Journal of Sports Sciences*, *39*(15), 1772–1779.

84. Hjorth, M. F., Chaput, J.-P., Ritz, C., Dalskov, S.-M., Andersen, R., Astrup, A., Tetens, I., Michaelsen, K. F., & Sjödin, A. (2014). Fatness predicts decreased physical activity and increased sedentary time, but not vice versa: support from a longitudinal study in 8- to 11-year-old children. *International Journal of Obesity*, *38*(7), 959–965.

85. Gonzalez, J. T., Batterham, A. M., Atkinson, G., & Thompson, D. (2023). Perspective: Is the response of human energy expenditure to increased physical activity additive or constrained? *Advances in Nutrition*.

86. Pontzer, H., Durazo-Arvizu, R., Dugas, L. R., Plange-Rhule, J., Bovet, P., Forrester, T. E., Lambert, E. V., Cooper, R. S., Schoeller, D. A., & Luke, A. (2016).

Constrained Total Energy Expenditure and Metabolic Adaptation to Physical Activity in Adult Humans. *Current Biology*, *26*(3), 410–417.

87. Pontzer, H., Raichlen, D. A., Wood, B. M., Emery Thompson, M., Racette, S. B., Mabulla, A. Z. P., & Marlowe, F. W. (2015). Energy expenditure and activity among Hadza hunter-gatherers. *American Journal of Human Biology*, *27*(5), 628–637.
88. King, N. A., Horner, K., Hills, A. P., Byrne, N. M., Wood, R. E., Bryant, E., Caudwell, P., Finlayson, G., Gibbons, C., Hopkins, M., Martins, C., & Blundell, J. E. (2012). Exercise, appetite and weight management: understanding the compensatory responses in eating behaviour and how they contribute to variability in exercise-induced weight loss. *British Journal of Sports Medicine*, *46*(5), 315–322.
89. Bell, J. A., Hamer, M., van Hees, V. T., Singh-Manoux, A., Kivimäki, M., & Sabia, S. (2015). Healthy obesity and objective physical activity1–3. *The American Journal of Clinical Nutrition*, *102*(2), 268–275.
90. Gaesser, G. A., & Angadi, S. S. (2021). Obesity treatment: Weight loss versus increasing fitness and physical activity for reducing health risks. *iScience*, 102995.
91. Mehta, T., Smith Jr., D. L., Muhammad, J., & Casazza, K. (2014). Impact of weight cycling on risk of morbidity and mortality. *Obesity Reviews*, *15*(11), 870–881.
92. Hall, K. D., & Kahan, S. (2018). Maintenance of Lost Weight and Long-Term Management of Obesity. *Medical Clinics of North America*, *102*(1), 183–197.
93. Wing, R. R., & Hill, J. O. (2001). Successful Weight Loss Maintenance. *Annual Review of Nutrition*, *21*(1), 323–341.
94. Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., Ekelund, U., & Lancet Physical Activity Series Working Group. (2012). Global physical activity

levels: surveillance progress, pitfalls, and prospects. *Lancet (London, England)*, *380*(9838), 247–257.

95. Raichlen, D. A., & Lieberman, D. E. (2022). The evolution of human step counts and its association with the risk of chronic disease. *Current Biology*, *32*(21), R1206–R1214.
96. Tudor-Locke, C., Craig, C. L., Brown, W. J., Clemes, S. A., De Cocker, K., Giles-Corti, B., Hatano, Y., Inoue, S., Matsudo, S. M., Mutrie, N., Oppert, J.-M., Rowe, D. A., Schmidt, M. D., Schofield, G. M., Spence, J. C., Teixeira, P. J., Tully, M. A., & Blair, S. N. (2011). How many steps/day are enough? for adults. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1), 79.
97. Althoff, T., Sosič, R., Hicks, J. L., King, A. C., Delp, S. L., & Leskovec, J. (2017). Large-scale physical activity data reveal worldwide activity inequality. *Nature Publishing Group*, *547*.
98. Morseth, B., & Hopstock, L. A. (2020). Time trends in physical activity in the Tromsø study: An update. *PLoS ONE*, *15*(4).
99. Stamatakis, E., Ekelund, U., & Wareham, N. J. (2007). Temporal trends in physical activity in England: The Health Survey for England 1991 to 2004. *Preventive Medicine*, *45*(6), 416–423.
100. Borodulin, K., Harald, K., Jousilahti, P., Laatikainen, T., Männistö, S., & Vartiainen, E. (2016). Time trends in physical activity from 1982 to 2012 in Finland. *Scandinavian Journal of Medicine and Science in Sports*, *26*(1), 93–100. Scopus.
101. Juneau, C.-E., & Potvin, L. (2010). Trends in leisure-, transport-, and work-related physical activity in Canada 1994-2005. *Preventive Medicine*, *51*(5), 384–386. Scopus.
102. Lamoureux, N. R., Fitzgerald, J. S., Norton, K. I., Sabato, T., Tremblay, M. S., & Tomkinson, G. R. (2019). Temporal Trends in the Cardiorespiratory Fitness of

2,525,827 Adults Between 1967 and 2016: A Systematic Review. *Sports Medicine*, *49*(1), 41–55. Scopus.

103. Bourke, M., Haddara, A., Loh, A., Carson, V., Breau, B., & Tucker, P. (2023). Adherence to the World Health Organization's physical activity recommendation in preschool-aged children: a systematic review and meta-analysis of accelerometer studies. *International Journal of Behavioral Nutrition and Physical Activity*, *20*(1), 52.

104. Aubert, S., Barnes, J. D., Abdeta, C., Nader, P. A., Adeniyi, A. F., Aguilar-Farias, N., Tenesaca, D. S. A., Bhawra, J., Brazo-Sayavera, J., Cardon, G., Chang, C. K., Delisle Nyström, C., Demetriou, Y., Draper, C. E., Edwards, L., Emeljanovas, A., Gába, A., Galaviz, K. I., González, S. A., … Tremblay, M. S. (2018). Global Matrix 3.0 Physical Activity Report Card Grades for Children and Youth: Results and Analysis From 49 Countries. *Journal of Physical Activity and Health*, *15*(s2), S251–S273.

105. Aadland, E., Kvalheim, O. M., Hansen, B. H., Kriemler, S., Ried-Larsen, M., Wedderkopp, N., Sardinha, L. B., Møller, N. C., Hallal, P. C., Anderssen, S. A., Northstone, K., & Andersen, L. B. (2020). The multivariate physical activity signature associated with metabolic health in children and youth: An International Children's Accelerometry Database (ICAD) analysis. *Preventive Medicine*, *141*, 106266.

106. Thomas, J. R., & Thomas, K. T. (1988). Development of gender differences in physical activity. *Quest*, *40*(3), 219–229.

107. Garcia, A. W., Pender, N. J., Antonakos, C. L., & Ronis, D. L. (1998). Changes in Physical Activity Beliefs and Behaviors of Boys and Girls Across the Transition to Junior High School. *Journal of Adolescent Health*, *22*(5), 394–402.

108. Steene-Johannessen, J., Anderssen, S. A., Kolle, E., Hansen, B. H., Bratteteig, M., Dalhaug, E. M., Andersen, L. B., Nystad, W., Ekelund, U., & Dalene, K. E. (2021). Temporal trends in physical activity levels across more than a decade - a national physical activity surveillance system among Norwegian children and adolescents. *The International Journal of Behavioral Nutrition and Physical Activity*, *18*(1), 55.

109. Booth, V. M., Rowlands, A. V., & Dollman, J. (2015). Physical activity temporal trends among children and adolescents. *Journal of Science and Medicine in Sport*, *18*(4), 418–425.

110. Muthuri, S. K., Wachira, L. J. M., Leblanc, A. G., Francis, C. E., Sampson, M., Onywera, V. O., & Tremblay, M. S. (2014). Temporal Trends and Correlates of Physical Activity, Sedentary Behaviour, and Physical Fitness among School-Aged Children in Sub-Saharan Africa: A Systematic Review. *International Journal of Environmental Research and Public Health 2014, Vol. 11, Pages 3327-3359*, *11*(3), 3327–3359.

111. Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. F., Martin, B. W., Alkandari, J. R., Andersen, L. B., Blair, S. N., Brownson, R. C., Bull, F. C., Craig, C. L., Ekelund, U., Goenka, S., Guthold, R., Hallal, P. C., Haskell, W. L., Heath, G. W., Inoue, S., … Sarmiento, O. L. (2012). Correlates of physical activity: Why are some people physically active and others not? *The Lancet*, *380*(9838), 258–271.

112. Trost, S. G., Pate, R. R., Sallis, J. F., Freedson, P. S., Taylor, W. C., Dowda, M., & Sirard, J. (2002). Age and gender differences in objectively measured physical activity in youth. In *Med. Sci. Sports Exerc* (Vol. 34, Issue 2, pp. 350–355). http://www.acsm-msse.org

113. Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2018). Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. *The Lancet Global Health*, *6*(10), e1077–e1086.

114. Van Tuyckom, C., Van De Velde, S., & Bracke, P. (2013). Does country-context matter? A cross-national analysis of gender and leisure time physical inactivity in Europe. *European Journal of Public Health*, *23*(3), 452–457.

115. Cillekens, B., Huysmans, M. A., Holtermann, A., van Mechelen, W., Straker, L., Krause, N., van der Beek, A. J., & Coenen, P. (2022). Physical activity at work may not be health enhancing. A systematic review with meta-analysis on the association between occupational physical activity and cardiovascular disease mortality covering 23 studies with 655 892 participants. *Scandinavian Journal of Work, Environment & Health*, *48*(2), 86–98.

116. Bann, D., Scholes, S., Fluharty, M., & Shure, N. (2019). Adolescents' physical activity: Cross-national comparisons of levels, distributions and disparities across 52 countries. *International Journal of Behavioral Nutrition and Physical Activity*, *16*(1), 141.

117. Wunsch, K., Nigg, C. R., Weyland, S., Jekauc, D., Niessner, C., Burchartz, A., Schmidt, S., Meyrose, A. K., Manz, K., Baumgarten, F., & Woll, A. (2021). The relationship of self-reported and device-based measures of physical activity and health-related quality of life in adolescents. *Health and Quality of Life Outcomes*, *19*(1), 1–10.

118. Troiano, R. P., McClain, J. J., Brychta, R. J., & Chen, K. Y. (2014). Evolution of accelerometer methods for physical activity research. *British Journal of Sports Medicine*, *48*(13), 1019–1023.

119. Hallal, P. C., Reichert, F. F., Clark, V. L., Cordeira, K. L., Menezes, A. M. B., Eaton, S., Ekelund, U., & Wells, J. C. (2013). Energy Expenditure Compared to Physical Activity Measured by Accelerometry and Self-Report in Adolescents: A Validation Study. *PLOS ONE*, *8*(11), e77036.

120. Konstabel, K., Veidebaum, T., Verbestel, V., Moreno, L. A., Bammann, K., Tornaritis, M., Eiben, G., Molnár, D., Siani, A., Sprengeler, O., Wirsik, N., Ahrens, W., & Pitsiladis, Y. (2014). Objectively measured physical activity in European children: the IDEFICS study. *International Journal of Obesity 2014 38:2*, *38*(2), S135–S143.

121. Choi, J., Lee, M., Lee, J. K., Kang, D., & Choi, J. Y. (2017). Correlates associated with participation in physical activity among adults: A systematic review of reviews and update. *BMC Public Health*, *17*(1), 356.

122. Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. F., Martin, B. W., Alkandari, J. R., Andersen, L. B., Blair, S. N., Brownson, R. C., Bull, F. C., Craig, C. L., Ekelund, U., Goenka, S., Guthold, R., Hallal, P. C., Haskell, W. L., Heath, G. W., Inoue, S., … Sarmiento, O. L. (2012). Correlates of physical activity: Why are some people physically active and others not? In *The Lancet* (Vol. 380, Issue 9838, pp. 258–271). Elsevier B.V.

123. Crimmins, E. M., Kim, J. K., & Solé-Auró, A. (2011). Gender differences in health: results from SHARE, ELSA and HRS. *European Journal of Public Health*, *21*(1), 81–91.

124. Christiani, Y., Byles, J. E., Tavener, M., & Dugdale, P. (2016). Gender Inequalities in Noncommunicable Disease Risk Factors Among Indonesian Urban Population. *Asia-Pacific Journal of Public Health*, *28*(2), 134–145.

125. Rahimi, E., Mohammadi, R., Mokhayeri, Y., & Nazari, S. S. H. (2023). Decomposing gender disparity in the risk of noncommunicable diseases in adults, Islamic Republic of Iran. *Eastern Mediterranean Health Journal*.

126. Sarma, M. S., Boyette, A. H., Lew-Levy, S., Miegakanda, V., Kilius, E., Samson, D. R., & Gettler, L. T. (2020). Sex differences in daily activity intensity and energy expenditure and their relationship to cortisol among <scp>BaYaka</scp> foragers from the Congo Basin. *American Journal of Physical Anthropology*, ajpa.24075.

127. Gurven, M., Jaeggi, A. V., Kaplan, H., & Cummings, D. (2013). Physical Activity and Modernization among Bolivian Amerindians. *PLoS ONE*, *8*(1), e55679.

128. Madimenos, F. C., Snodgrass, J. J., Blackwell, A. D., Liebert, M. A., & Sugiyama, L. S. (2011). Physical activity in an indigenous Ecuadorian forager-horticulturalist population as measured using accelerometry. *American Journal of Human Biology*, *23*(4), 488–497.

129. Hagino, I., & Yamauchi, T. (2014). Daily Physical Activity and Time-Space Using of Pygmy Hunter-Gatherers' Children in Southeast Cameroon. In *Dynamics of Learning in Neanderthals and Modern Humans Volume 2* (pp. 91–97). Springer Japan.

130. Raichlen, D. A., Pontzer, H., Harris, J. A., Mabulla, A. Z. P., Marlowe, F. W., Josh Snodgrass, J., Eick, G., Colette Berbesque, J., Sancilio, A., & Wood, B. M. (2017). Physical activity patterns and biomarkers of cardiovascular disease risk in hunter-gatherers. *American Journal of Human Biology*, *29*(2), e22919.

131. Raichlen, D. A., Pontzer, H., Zderic, T. W., Harris, J. A., Mabulla, A. Z. P., Hamilton, M. T., & Wood, B. M. (2020). Sitting, squatting, and the evolutionary biology of human inactivity. *Proceedings of the National Academy of Sciences*, *117*(13), 7115–7121.

132. Marlowe, F. W. (2007). Hunting and Gathering. *Cross-Cultural Research*, *41*(2), 170–195.

133. Hamilton, W. D. (1964). The genetical evolution of social behaviour. I. *Journal of Theoretical Biology*, *7*(1), 1–16.

134. Williams, G. C., & Nesse, R. M. (1991). The dawn of Darwinian medicine. *Quarterly Review of Biology*, *66*(1), 1–22.

135. Eaton, S. B., Konner, M., & Shostak, M. (1988). Stone agers in the fast lane: Chronic degenerative diseases in evolutionary perspective. *The American Journal of Medicine*, *84*(4), 739–749.

136. Hill, K. (1993). Life history theory and evolutionary anthropology. *Evolutionary Anthropology: Issues, News, and Reviews*, *2*(3), 78–88.

137. Kramer, K. L., & Ellison, P. T. (2010). Pooled energy budgets: Resituating human energy -allocation trade-offs. *Evolutionary Anthropology: Issues, News, and Reviews*, *19*(4), 136–147.

138. Promislow, D. E. L., & Harvey, P. H. (1990). Living fast and dying young: A comparative analysis of life-history variation among mammals. *Journal of Zoology*, *220*(3), 417–437.

139. Del Giudice, M., & Belsky, J. (2011). The Development of Life History Strategies: Toward a Multi-Stage Theory. In *The Evolution of Personality and Individual Differences* (pp. 154–176). Oxford Univ Press.

140. Chua, K. J., Lukaszewski, A. W., Grant, D. M., & Sng, O. (2017). Human Life History Strategies. *Evolutionary Psychology*, *15*(1), 147470491667734.

141. Migliano, A. B., Vinicius, L., & Lahr, M. M. (2007). Life history trade-offs explain the evolution of human pygmies. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(51), 20216–20219.

142. Perrin, N., & Sibly, R. M. (1993). Dynamic Models of Energy Allocation and Investment. *Source: Annual Review of Ecology and Systematics*, *24*, 379–410.

143. Hawkes, K., O'Connell, J. F., & Rogers, L. (1997). The behavioral ecology of modern hunter-gatherers, and human evolution. *Trends in Ecology & Evolution*, *12*(1), 29–32.

144. Cunningham, R. M., Walton, M. A., & Carter, P. M. (2018). The Major Causes of Death in Children and Adolescents in the United States. *Https://Doi.Org/10.1056/NEJMsr1804754*, *379*(25), 2468–2475.

145. Gurven, M., & Kaplan, H. (2007). Longevity Among Hunter- Gatherers: A Cross-Cultural Examination. *Population and Development Review*, *33*(2), 321–365.

146. Pontzer, H., Yamada, Y., Sagayama, H., Ainslie, P. N., Andersen, L. F., Anderson, L. J., Arab, L., Baddou, I., Bedu-Addo, K., Blaak, E. E., Blanc, S., Bonomi, A. G., Bouten, C. V. C., Bovet, P., Buchowski, M. S., Butte, N. F., Camps, S. G., Close, G. L., Cooper, J. A., … Speakman, J. R. (2021). Daily energy expenditure through the human life course. *Science*, *373*(6556), 808–812.

147. Cole, T. J. (2022). Growth references and standards. In *Human Growth and Development* (pp. 391–422). Elsevier.

148. McDade, T. W. (2003). Life history theory and the immune system: Steps toward a human ecological immunology. *American Journal of Physical Anthropology*, *122*(S37), 100–125.

149. Garcia, A. R., Blackwell, A. D., Trumble, B. C., Stieglitz, J., Kaplan, H., & Gurven, M. D. (2020). Evidence for height and immune function trade-offs among preadolescents in a high pathogen population. *Evolution, Medicine, and Public Health*, *2020*(1), 86–99.

150. Bonduriansky, R., Maklakov, A., Zajitschek, F., & Brooks, R. (2008). Sexual selection, sexual conflict and the evolution of ageing and life span. *Functional Ecology*, *22*(3), 443–453.

151. Butte, N. F., & King, J. C. (2005). Energy requirements during pregnancy and lactation. *Public Health Nutrition*, *8*(7a), 1010–1027.

152. Chen, A., & Rogan, W. J. (2004). Breastfeeding and the risk of postneonatal death in the United States. *Pediatrics*, *113*(5), e435–e439.

153. Lawson, D. W., Alvergne, A., & Gibson, M. A. (2012). The life-history trade-off between fertility and child survival. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1748), 4755–4764.

154. Marlowe, F. (1999). Male Care and Mating Effort among Hadza Foragers. In *Behavioral Ecology and Sociobiology* (Vol. 46, pp. 57–64). Springer.

155. Vashro, L., & Cashdan, E. (2014). *Evolution and Human Behavior Spatial cognition, mobility, and reproductive suc-cess in northwestern Namibia*.

156. Kaplan, H. S., Hooper, P. L., & Gurven, M. (2009). The evolutionary and ecological roots of human social organization. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1533), 3289–3299.

157. Pontzer, H., Wood, B. M., & Raichlen, D. A. (2018). Hunter-gatherers as models in public health. *Obesity Reviews*, *19*, 24–35.

158. Pontzer, H. (2015). *Constrained Total Energy Expenditure and the Evolutionary Biology of Energy Balance*.

159. Gluckman, P. D., & Hanson, M. A. (2006). Evolution, development and timing of puberty. *Trends in Endocrinology & Metabolism*, *17*(1), 7–12.

160. Trumble, B. C., Pontzer, H., Stieglitz, J., Cummings, D. K., Wood, B., Emery Thompson, M., Raichlen, D., Beheim, B., Yetish, G., Kaplan, H., & Gurven, M.

(2023). Energetic costs of testosterone in two subsistence populations. *American Journal of Human Biology*, *n/a*(n/a), e23949.

161. Hoogeveen, A. R., & Zonderland, M. L. (1996). Relationships between testosterone, cortisol and performance in professional cyclists. *International Journal of Sports Medicine*, *17*(6), 423–428.
162. Jasienska, G., Ziomkiewicz, A., Thune, I., Lipson, S. F., & Ellison, P. T. (2006). Habitual physical activity and estradiol levels in women of reproductive age. *European Journal of Cancer Prevention*, *15*(5). https://journals.lww.com/eurjcancerprev/Fulltext/2006/10000/Habitual_physical_activity_and_estradiol_levels_in.9.aspx
163. Silverman, M. N., & Deuster, P. A. (2014). Biological mechanisms underlying the role of physical fitness in health and resilience. *Interface Focus*, *4*(5), 20140040.
164. Wen, C. P., Wai, J. P. M., Tsai, M. K., Yang, Y. C., Cheng, T. Y. D., Lee, M. C., Chan, H. T., Tsao, C. K., Tsai, S. P., & Wu, X. (2011). Minimum amount of physical activity for reduced mortality and extended life expectancy: a prospective cohort study. *The Lancet*, *378*(9798), 1244–1253.
165. Ekelund, U., Ward, H. A., Norat, T., Luan, J., May, A. M., Weiderpass, E., Sharp, S. J., Overvad, K., Østergaard, J. N., Tjønneland, A., Johnsen, N. F., Mesrine, S., Fournier, A., Fagherazzi, G., Trichopoulou, A., Lagiou, P., Trichopoulos, D., Li, K., Kaaks, R., … Riboli, E. (2015). Physical activity and all-cause mortality across levels of overall and abdominal adiposity in European men and women: The European prospective investigation into cancer and nutrition study (EPIC). *American Journal of Clinical Nutrition*, *101*(3), 613–621.
166. Lew-Levy, S., Kruuk, L., Neiman, M., Brosnan, S., Bombjaková, D., Milks, A., Kiabiya Ntamboudila, F., Kline, M. A., & Broesch, T. (2022). Costly teaching

contributes to the acquisition of spear hunting skill among BaYaka forager adolescents. *Proceedings of the Royal Society B: Biological Sciences*, *289*(1974).

167. Larsen, C. S. (2006). The agricultural revolution as environmental catastrophe: Implications for health and lifestyle in the Holocene. *Quaternary International*, *150*(1), 12–20.

168. Evershed, R. P., Davey Smith, G., Roffet-Salque, M., Timpson, A., Diekmann, Y., Lyon, M. S., Cramp, L. J. E., Casanova, E., Smyth, J., Whelton, H. L., Dunne, J., Brychova, V., Šoberl, L., Gerbault, P., Gillis, R. E., Heyd, V., Johnson, E., Kendall, I., Manning, K., … Thomas, M. G. (2022). Dairying, diseases and the evolution of lactase persistence in Europe. *Nature*, 1–10.

169. Dunsworth, H. M. (2010). Origin of the Genus Homo. *Evolution: Education and Outreach*, *3*(3), 353–366.

170. Stringer, C. (2016). The origin and evolution of Homo sapiens. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1698), 20150237.

171. Kelly, S. A., Panhuis, T. M., & Stoehr, A. M. (2012). Phenotypic plasticity: molecular mechanisms and adaptive significance. *Comprehensive Physiology*, *2*(2), 1417–1439.

172. Longman, D. P., Wells, J. C. K., & Stock, J. T. (2020). Human athletic paleobiology; using sport as a model to investigate human evolutionary adaptation. *American Journal of Physical Anthropology*, *171*(S70), 42–59.

173. Bramble, D. M., & Lieberman, D. E. (2004). Endurance running and the evolution of Homo. *Nature*, *432*(7015), 345–352.

174. Zihlman, A. L., & Bolter, D. R. (2015). Body composition in Pan paniscus compared with Homo sapiens has implications for changes during human evolution. *Proceedings of the National Academy of Sciences of the United States of America*, *112*(24), 7466–7471.

175. Lieberman, D. E. (2015). Human Locomotion and Heat Loss: An Evolutionary Perspective. *Compr Physiol*, *5*, 99–117.

176. Ko, K. H. (2015). Origins of Bipedalism. *Brazilian Archives of Biology and Technology*, *58*(6), 929–934.

177. Hatala, K. G., Demes, B., & Richmond, B. G. (2016). Laetoli footprints reveal bipedal gait biomechanics different from those of modern humans and chimpanzees. *Proceedings. Biological Sciences*, *283*(1836), 20160235.

178. Rodman, P. S., & McHenry, H. M. (1980). Bioenergetics and the origin of hominid bipedalism. *American Journal of Physical Anthropology*, *52*(1), 103–106.

179. Wheeler, P. E. (1984). The evolution of bipedality and loss of functional body hair in hominids. *Journal of Human Evolution*, *13*(1), 91–98.

180. Lewis, M. E. (1997). Carnivoran paleoguilds of Africa: implications for hominid food procurement strategies. *Journal of Human Evolution*, *32*(2–3), 257–288.

181. Pontzer, H., Raichlen, D. A., & Rodman, P. S. (2014). Bipedal and quadrupedal locomotion in chimpanzees. *Journal of Human Evolution*, *66*, 64–82.

182. Hoppeler, H., & Flück, M. (2002). Normal mammalian skeletal muscle and its phenotypic plasticity. *Journal of Experimental Biology*, *205*(15), 2143–2152.

183. Nettle, D., & Bateson, M. (2015). Adaptive developmental plasticity: what is it, how can we recognize it and when can it evolve? *Proceedings of the Royal Society B: Biological Sciences*, *282*(1812), 20151005.

184. Woodburn, J. (1982). Egalitarian Societies. In *New Series* (Vol. 17, Issue 3, pp. 431–451).

185. Page, A. E., & French, J. C. (2020). Reconstructing prehistoric demography: What role for extant hunter-gatherers? *Evolutionary Anthropology*, *29*(6), 332–345.

186. Cordain, L., Miller, J. B., Eaton, S. B., Mann, N., Holt, S. H., & Speth, J. D. (2000). Plant-animal subsistence ratios and macronutrient energy estimations in

worldwide hunter-gatherer diets. *The American Journal of Clinical Nutrition*, *71*(3), 682–692.

187. Pontzer, H., & Wood, B. M. (2021). Effects of Evolution, Ecology, and Economy on Human Diet: Insights from Hunter-Gatherers and Other Small-Scale Societies. *Annual Review of Nutrition*, *41*(1).

188. Salali, G. D., Dyble, M., Chaudhary, N., Sikka, G., Derkx, I., Keestra, S. M., Smith, D., Thompson, J., Vinicius, L., & Migliano, A. B. (2020). Global WEIRDing: Transitions in Wild Plant Knowledge and Treatment Preferences in Congo Hunter-Gatherers. *Evolutionary Human Sciences*, *2*, 1–16.

189. Crittenden, A. N., & Schnorr, S. L. (2017). Current views on hunter-gatherer nutrition and the evolution of the human diet. *American Journal of Physical Anthropology*, *162*(S63), 84–109.

190. Dyble, M., Salali, G. D., Chaudhary, N., Page, A., Smith, D., Thompson, J., Vinicius, L., Mace, R., & Migliano, A. B. (2015). Sex equality can explain the unique social structure of hunter-gatherer bands. *Science*, *348*(6236), 796 LP – 798.

191. Hawkes, K., O'Connell, J. F., & Coxworth, J. E. (2010). Family Provisioning Is Not the Only Reason Men Hunt: A Comment on Gurven and Hill. *Current Anthropology*, *51*(2), 259–264.

192. Anderson, A., Chilczuk, S., Nelson, K., Ruther, R., & Wall-Scheffler, C. (2023). The Myth of Man the Hunter: Women's contribution to the hunt across ethnographic contexts. *PLOS ONE*, *18*(6), e0287101.

193. Carter, G. G., Farine, D. R., & Wilkinson, G. S. (2017). Social bet-hedging in vampire bats. *Biology Letters*, *13*(5), 20170112.

194. Salali, G. D., & Migliano, A. B. (2015). Future Discounting in Congo Basin Hunter-Gatherers Declines with Socio-Economic Transitions. *PLOS ONE , 10 (9) , Article E0137806. (2015)*, *10*(9), e0137806.

195. Kaplan, H. S., & Bock, J. (2001). Fertility Theory: Embodied-capital Theory of Life History Evolution. In N. J. Smelser & P. B. Baltes (Eds.), *International Encyclopedia of the Social & Behavioral Sciences* (pp. 5561–5568). Pergamon.

196. Bjorklund, D. F., & Ellis, B. J. (2014). Children, childhood, and development in evolutionary perspective. *Developmental Review*, *34*(3), 225–264.

197. Del Giudice, M., Angeleri, R., & Manera, V. (2009). The juvenile transition: A developmental switch point in human life history. *Developmental Review*, *29*(1), 1–31.

198. Dunsworth, H. M., Warrener, A. G., Deacon, T., Ellison, P. T., & Pontzer, H. (2012). Metabolic hypothesis for human altriciality. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(38), 15212–15216.

199. Dosman, C. F., Andrews, D., & Goulden, K. J. (2012). Evidence-based milestone ages as a framework for developmental surveillance. *Paediatrics & Child Health*, *17*(10), 561–568.

200. Salali, G. D., Chaudhary, N., Bouer, J., Thompson, J., Vinicius, L., & Migliano, A. B. (2019). Development of social learning and play in BaYaka hunter-gatherers of Congo. *Scientific Reports*, *9*(1), 11080.

201. Lounassalo, I., Salin, K., Kankaanpää, A., Hirvensalo, M., Palomäki, S., Tolvanen, A., Yang, X., & Tammelin, T. H. (2019). Distinct trajectories of physical activity and related factors during the life course in the general population: a systematic review. *BMC Public Health*, *19*(1), 271.

202. Lew-Levy, S., Boyette, A. H., Crittenden, A. N., Hewlett, B. S., & Lamb, M. E. (2019). Gender-Typed and Gender-Segregated Play Among Tanzanian Hadza and Congolese BaYaka Hunter-Gatherer Children and Adolescents. *Child Development*, cdev.13306.

203. Urlacher, S. S. (2023). The energetics of childhood: Current knowledge and insights into human variation, evolution, and health. *American Journal of Biological Anthropology*.

204. Bombjaková, D., Lew-Levy, S., Duda, R., Loubelo, G., & Lewis, J. (2020). BaYaka education. *Hunter Gatherer Research*, *6*(1–2), 87–114.

205. Lew-Levy, S., Reckin, R., Kissler, S. M., Pretelli, I., Boyette, A. H., Crittenden, A. N., Hagen, R. V., Haas, R., Kramer, K. L., Koster, J., O'Brien, M. J., Sonoda, K., Surovell, T. A., Stieglitz, J., Tucker, B., Lavi, N., Ellis-Davies, K., & Davis, H. E. (2022). Socioecology shapes child and adolescent time allocation in twelve hunter-gatherer and mixed-subsistence forager societies. *Scientific Reports*, *12*(1), 8054.

206. Koster, J., McElreath, R., Hill, K., Yu, D., Shepard, G., Van Vliet, N., Gurven, M., Trumble, B., Bird, R. B., Bird, D., Codding, B., Coad, L., Pacheco-Cobos, L., Winterhalder, B., Lupo, K., Schmitt, D., Sillitoe, P., Franzen, M., Alvard, M., … Ross, C. (2020). The life history of human foraging: Cross-cultural and individual variation. *Science Advances*, *6*(26), 9070–9094.

207. Hochberg, Z., Gawlik, A., & Walker, R. S. (2011). Evolutionary fitness as a function of pubertal age in 22 subsistence-based traditional societies. *International Journal of Pediatric Endocrinology*, *2011*(1), 2.

208. Lacroix, A. E., Gondal, H., Shumway, K. R., & Langaker, M. D. (2023). Physiology, Menarche. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK470216/

209. Parent, A.-S., Teilmann, G., Juul, A., Skakkebaek, N. E., Toppari, J., & Bourguignon, J.-P. (2003). The timing of normal puberty and the age limits of sexual precocity: variations around the world, secular trends, and changes after migration. *Endocrine Reviews*, *24*(5), 668–693.

210. de Muinck Keizer-Schrama, S. M. P. F., & Mul, D. (2001). Trends in pubertal development in Europe. *Human Reproduction Update*, *7*(3), 287–291.

211. Nguyen, N. T. K., Fan, H.-Y., Tsai, M.-C., Tung, T.-H., Huynh, Q. T. V., Huang, S.-Y., & Chen, Y. C. (2020). Nutrient Intake through Childhood and Early Menarche Onset in Girls: Systematic Review and Meta-Analysis. *Nutrients*, *12*(9), 2544.

212. Juul, F., & Hemmingsson, E. (2015). Trends in consumption of ultra-processed foods and obesity in Sweden between 1960 and 2010. *Public Health Nutrition*, *18*(17), 3096–3107.

213. Vandevijvere, S., Jaacks, L. M., Monteiro, C. A., Moubarac, J.-C., Girling-Butcher, M., Lee, A. C., Pan, A., Bentham, J., & Swinburn, B. (2019). Global trends in ultraprocessed food and drink product sales and their association with adult body mass index trajectories. *Obesity Reviews: An Official Journal of the International Association for the Study of Obesity*, *20 Suppl 2*, 10–19.

214. Bigna, J. J., & Noubiap, J. J. (2019). The rising burden of non-communicable diseases in sub-Saharan Africa. *The Lancet Global Health*, *7*(10), e1295–e1296.

215. Rapp, D., Scharhag, J., Wagenpfeil, S., & Scholl, J. (2018). Reference values for peak oxygen uptake: cross-sectional analysis of cycle ergometry-based cardiopulmonary exercise tests of 10 090 adult German volunteers from the Prevention First Registry. *BMJ Open*, *8*(3), e018697.

216. Kaplan, H., Thompson, R. C., Trumble, B. C., Wann, L. S., Allam, A. H., Beheim, B., Frohlich, B., Sutherland, M. L., Sutherland, J. D., Stieglitz, J., Rodriguez, D. E., Michalik, D. E., Rowan, C. J., Lombardi, G. P., Bedi, R., Garcia, A. R., Min, J. K., Narula, J., Finch, C. E., … Thomas, G. S. (2017). Coronary atherosclerosis in indigenous South American Tsimane: a cross-sectional cohort study. *The Lancet*, *389*(10080), 1730–1739.

217. Joffres, M., Falaschetti, E., Gillespie, C., Robitaille, C., Loustalot, F., Poulter, N., McAlister, F. A., Johansen, H., Baclic, O., & Campbell, N. (2013). Hypertension prevalence, awareness, treatment and control in national surveys from England, the USA and Canada, and correlation with stroke and ischaemic heart disease mortality: a cross-sectional study. *BMJ Open*, *3*(8), e003423.

218. Lifestyles Team, NHS Digital. (2020). *Health Survey For England 2019*.

219. O'Keefe, J. H., Vogel, R., Lavie, C. J., & Cordain, L. (2011). Exercise Like a Hunter-Gatherer: A Prescription for Organic Physical Fitness. *Progress in Cardiovascular Diseases*, *53*(6), 471–479.

220. Boullosa, D. A., Abreu, L., Varela-Sanz, A., & Mujika, I. (2013). Do olympic athletes train as in the paleolithic era? *Sports Medicine*, *43*(10), 909–917.

221. Tucker, J. M., Welk, G. J., & Beyler, N. K. (2011). Physical activity in U.S. adults: Compliance with the physical activity guidelines for Americans. *American Journal of Preventive Medicine*, *40*(4), 454–461.

222. Dugas, L. R., Harders, R., Merrill, S., Ebersole, K., Shoham, D. A., Rush, E. C., Assah, F. K., Forrester, T., Durazo-Arvizu, R. A., & Luke, A. (2011). Energy expenditure in adults living in developing compared with industrialized countries: A meta-analysis of doubly labeled water studies. *American Journal of Clinical Nutrition*, *93*(2), 427–441.

223. Dugas, L. R., Bovet, P., Forrester, T. E., Lambert, E. V., Plange-Rhule, J., Durazo-Arvizu, R. A., Shoham, D., Kroff, J., Cao, G., Cooper, R. S., Brage, S., Ekelund, U., & Luke, A. (2014). Comparisons of intensity-duration patterns of physical activity in the US, Jamaica and 3 African countries. *BMC Public Health*, *14*(1), 1–17.

224. Sayre, M. K., Pontzer, H., Alexander, G. E., Wood, B. M., Pike, I. L., Mabulla, A. Z. P., & Raichlen, D. A. (2020). *Ageing and physical function in East African foragers and pastoralists*.

225. Yamauchi, T., Umezaki, M., & Ohtsuka, R. (2001). Physical activity and subsistence pattern of the Huli, a Papua New Guinea Highland population. *American Journal of Physical Anthropology*, *114*(3), 258–268.

226. Hamer, M., Kivimaki, M., & Steptoe, A. (n.d.). *Longitudinal patterns in physical activity and sedentary behaviour from mid-life to early old age: a substudy of the Whitehall II cohort*.

227. Biswas, A., Oh, P. I., Faulkner, G. E., Bajaj, R. R., Silver, M. A., Mitchell, M. S., & Alter, D. A. (2015). Sedentary Time and Its Association With Risk for Disease Incidence, Mortality, and Hospitalization in Adults. *Annals of Internal Medicine*, *162*(2), 123–132.

228. Tremblay, M. S., LeBlanc, A. G., Kho, M. E., Saunders, T. J., Larouche, R., Colley, R. C., Goldfield, G., & Gorber, S. C. (2011). Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1), 98.

229. Froehle, A. W., Wells, G. K., Pollom, T. R., Mabulla, A. Z. P., Lew-Levy, S., & Crittenden, A. N. (2019). Physical activity and time budgets of Hadza forager children: Implications for self-provisioning and the ontogeny of the sexual division of labor. *American Journal of Human Biology*, *31*(1), e23209.

230. Mekary, R. A., & Ding, E. L. (2019). Isotemporal substitution as the gold standard model for physical activity epidemiology: Why it is the most appropriate for activity time research. *International Journal of Environmental Research and Public Health*, *16*(5), 797.

231. Buman, M. P., Winkler, E. A. H., Kurka, J. M., Hekler, E. B., Baldwin, C. M., Owen, N., Ainsworth, B. E., Healy, G. N., & Gardiner, P. A. (2014). *Reallocating Time to Sleep, Sedentary Behaviors, or Active Behaviors: Associations With Cardiovascular Disease Risk Biomarkers, NHANES 2005–2006* [Article]. *179*(3), 323–334.

232. Pearce, N. (2013). Global epidemiology: the importance of international comparisons and collaborations. *Open Access Epidemiology*, *1*(2), 15.

233. Kromhout, D., Menotti, A., Kesteloot, H., & Sans, S. (2002). Prevention of coronary heart disease by diet and lifestyle evidence from prospective cross-cultural, cohort, and intervention studies. *Circulation*, *105*(7), 893–898.

234. Campbell, O. L. K., Bann, D., & Patalay, P. (2021). The gender gap in adolescent mental health: a cross-national investigation of 566,829 adolescents across 73 countries. *SSM - Population Health*, 100742.

235. Asher, M. I., Montefort, S., Björkstén, B., Lai, C. K., Strachan, D. P., Weiland, S. K., & Williams, H. (2006). Worldwide time trends in the prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and eczema in childhood: ISAAC Phases One and Three repeat multicountry cross-sectional surveys. *Lancet*, *368*(9537), 733–743.

236. Pearce, N., Lawlor, D. A., & Brickley, E. B. (2020). Comparisons between countries are essential for the control of COVID-19. *International Journal of Epidemiology*, *49*(4), 1059–1062.

237. Bann, D., Wright, L., & Cole, T. J. (2022). Risk factors relate to the variability of health outcomes as well as the mean: A GAMLSS tutorial. *eLife*, *11*.

238. Mills, H. L., Higgins, J. P. T., Morris, R. W., Kessler, D., Heron, J., Wiles, N., Davey Smith, G., & Tilling, K. (2021). Detecting Heterogeneity of Intervention Effects

Using Analysis and Meta-analysis of Differences in Variance Between Trial Arms. *Epidemiology (Cambridge, Mass.)*, *32*(6), 846.

239. Rose, G. (2001). Sick individuals and sick populations. *International Journal of Epidemiology*, *30*(3), 427–432.

240. Rose, G., Khaw, K.-T., & Marmot, M. (2008). *Rose's strategy of preventative medicine*. Oxford University Press.

241. Ahern, J., Jones, M. R., Bakshis, E., & Galea, S. (2008). Revisiting Rose: Comparing the Benefits and Costs of Population-Wide and Targeted Interventions. *The Milbank Quarterly*, *86*(4), 581–600.

242. Zulman, D. M., Vijan, S., Omenn, G. S., & Hayward, R. A. (2008). The Relative Merits of Population-Based and Targeted Prevention Strategies. *The Milbank Quarterly*, *86*(4), 557–580.

243. Keyes, K. M., & Galea, S. (2016). *Population Health Science*. Oxford University Press.

244. McDade, T. W., & Nyberg, C. H. (2010). Acculturation and Health. In M. P. Muehlenbein (Ed.), *Human Evolutionary Biology* (pp. 581–602). Cambridge University Press.

245. Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and Brain Sciences*, *33*(2–3), 61–83.

246. Sankoh, O., & Byass, P. (2012). The INDEPTH Network: filling vital gaps in global epidemiology. *International Journal of Epidemiology*, *41*(3), 579–588.

247. Claessens, S., Kyritsis, T., & Atkinson, Q. D. (2023). Cross-national analyses require additional controls to account for the non-independence of nations. *Nature Communications*, *14*(1), 1–13.

248. Verdu, P., & Destro-Bisol, G. (2012). African Pygmies, what's behind a name? *Human Biology*, *84*(1), 1–10.

249. Bahuchet, S. (2012). Changing Language, Remaining Pygmy. *Human Biology*, *84*(1), 11–43.

250. Lewis, J. (2015). Where goods are free but knowledge costs. *Hunter Gatherer Research*, *1*(1).

251. Olivero, J., Fa, J. E., Farfán, M. A., Lewis, J., Hewlett, B., Breuer, T., Carpaneto, G. M., Fernández, M., Germi, F., Hattori, S., Head, J., Ichikawa, M., Kitanaishi, K., Knights, J., Matsuura, N., Migliano, A., Nese, B., Noss, A., Ekoumou, D. O., … Nasi, R. (2016). Distribution and Numbers of Pygmies in Central African Forests. *PLOS ONE*, *11*(1), e0144499.

252. Kitanishi, K. (1995). Seasonal Changes in the Subsistence Activities and Food Intake of the Aka Hunter-Gatherers in Northeastern Congo. *African Study Monographs*, *16*(2), 73–118.

253. Lew-Levy, S., Ringen, E. J., Crittenden, A. N., Mabulla, I. A., Broesch, T., & Kline, M. A. (2021). The Life History of Learning Subsistence Skills among Hadza and BaYaka Foragers from Tanzania and the Republic of Congo. *Human Nature*, 1–32.

254. Jang, H., Janmaat, K. R. L., Kandza, V., & Boyette, A. H. (2022). Girls in early childhood increase food returns of nursing women during subsistence activities of the BaYaka in the Republic of Congo. *Proceedings of the Royal Society B: Biological Sciences*, *289*(1987), 20221407.

255. Boyette, A. H., & Hewlett, B. S. (2017). Autonomy, Equality, and Teaching among Aka Foragers and Ngandu Farmers of the Congo Basin. *Human Nature*, *28*(3), 289–322.

256. Boyette, A. H., & Lew-Levy, S. (2020). Socialization, Autonomy, and Cooperation: Insights from Task Assignment Among the Egalitarian BaYaka. *Ethos*, *48*(3), 400–418.

257. James, J. (2007). *Logging with care in Congo*. BBC News. http://news.bbc.co.uk/1/hi/programmes/from_our_own_correspondent/7028445.stm

258. Diekmann, Y., Smith, D., Gerbault, P., Dyble, M., Page, A. E., Chaudhary, N., Migliano, A. B., & Thomas, M. G. (2017). Accurate age estimation in small-scale societies. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(31), 8205–8210.

259. Sherar, L. B., Griew, P., Esliger, D. W., Cooper, A. R., Ekelund, U., Judge, K., & Riddoch, C. (2011). International children's accelerometry database (ICAD): Design and methods. *BMC Public Health*, *11*(1), 1–13.

260. Komanduri, S., Jadhao, Y., Guduru, S. S., Cheriyath, P., & Wert, Y. (2017). Prevalence and risk factors of heart failure in the USA: NHANES 2013 – 2014 epidemiological follow-up study. *Journal of Community Hospital Internal Medicine Perspectives*, *7*(1), 15–20.

261. Connelly, R., & Platt, L. (2014). Cohort Profile: UK Millennium Cohort Study (MCS). *International Journal of Epidemiology*, *43*(6), 1719–1725.

262. Griffiths, L., Rich, C., Geraci, M., Sera, F., Cortina-Borja, M., Pouliou, T., Platt, L., Johnson, J., & Dezateux, C. (2013). *Technical report on the enhancement of Millennium Cohort Study data with accelerometer-derived measures of physical activity and sedentary behaviour in seven year olds*.

263. Gilbert, E., Conolly, A., Tietz, S., Calderwood, L., & Rose, N. (2017). Measuring young people's physical activity using accelerometers in the UK Millennium Cohort Study. *Centre for Longitudinal Studies Working Paper*.

264. Hills, A. P., Mokhtar, N., & Byrne, N. M. (2014). Assessment of physical activity and energy expenditure: an overview of objective measures. *Frontiers in Nutrition*, *1*, 5.

265. Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett, D. R., Tudor-Locke, C., Greer, J. L., Vezina, J., Whitt-Glover, M. C., Leon, A. S., Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett, D. R., Tudor-Locke, C., Greer, J. L., Vezina, J., Whitt-Glover, M. C., & Leon, A. S. (2011). Compendium of Physical Activities: A Second Update of Codes and MET Values. *Med. Sci. Sports Exerc*, *43*(8), 1575–1581.

266. Sirard, J. R., & Pate, R. R. (2001). Physical Activity Assessment in Children and Adolescents. *Sports Medicine*, *31*(6), 439–454.

267. Phillips, S. M., Summerbell, C., Hobbs, M., Hesketh, K. R., Saxena, S., Muir, C., & Hillier-Brown, F. C. (2021). A systematic review of the validity, reliability, and feasibility of measurement tools used to assess the physical activity and sedentary behaviour of pre-school aged children. *International Journal of Behavioral Nutrition and Physical Activity*, *18*(1), 141.

268. Dowd, K. P., Szeklicki, R., Minetto, M. A., Murphy, M. H., Polito, A., Ghigo, E., van der Ploeg, H., Ekelund, U., Maciaszek, J., Stemplewski, R., Tomczak, M., & Donnelly, A. E. (2018). A systematic literature review of reviews on techniques for physical activity measurement in adults: A DEDIPAC study. *International Journal of Behavioral Nutrition and Physical Activity*, *15*(1), 1–33.

269. Prince, S. A. S. A. S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Connor Gorber, S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *5*(1), 56.

270. Kohl, H. W., Fulton, J. E., & Caspersen, C. J. (2000). Assessment of Physical Activity among Children and Adolescents: A Review and Synthesis. *Preventive Medicine*, *31*(2), S54–S76.

271. Saint-Maurice, P. F., & Welk, G. J. (2015). Validity and Calibration of the Youth Activity Profile. *PLOS ONE*, *10*(12), e0143949.

272. Fiedler, J., Eckert, T., Burchartz, A., Woll, A., & Wunsch, K. (2021). Comparison of Self-Reported and Device-Based Measured Physical Activity Using Measures of Stability, Reliability, and Validity in Adults and Children. *Sensors*, *21*(8), 2672.

273. Duncan, M. J., Roscoe, C. M. P., Faghy, M., Tallis, J., & Eyre, E. L. J. (2019). Estimating Physical Activity in Children Aged 8–11 Years Using Accelerometry: Contributions From Fundamental Movement Skills and Different Accelerometer Placements. *Frontiers in Physiology*, *10*, 242.

274. Pedišić, Ž., & Bauman, A. (2015). Accelerometer-based measures in physical activity surveillance: current practices and issues. *British Journal of Sports Medicine*, *49*(4), 219–223.

275. Guinhouya, B. C., Samouda, H., & de Beaufort, C. (2013). Level of physical activity among children and adolescents in Europe: a review of physical activity assessed objectively by accelerometry. *Public Health*, *127*(4), 301–311.

276. Kerr, J., Marinac, C. R., Ellis, K., Godbole, S., Hipp, A., Glanz, K., Mitchell, J., Laden, F., James, P., & Berrigan, D. (2017). Comparison of Accelerometry Methods for Estimating Physical Activity. *Medicine and Science in Sports and Exercise*, *49*(3), 617–624.

277. Stevens, M. L., Gupta, N., Eroglu, E. I., Crowley, P. J., Eroglu, B., Bauman, A., Granat, M., Straker, L., Palm, P., Stenholm, S., Aadahl, M., Mork, P., Chastin, S., Rangul, V., Hamer, M., Koster, A., Holtermann, A., & Stamatakis, E. (2020). Thigh-worn accelerometry for measuring movement and posture across the 24-hour cycle: a scoping review and expert statement. *BMJ Open Sport & Exercise Medicine*, *6*(1), e000874.

278. Pontzer, H. (2022). *Burn*. https://www.penguin.co.uk/books/312914/burn-by-pontzer-herman/9780141990170

279. Lemay, M., Bertschi, M., Sola, J., Renevey, P., Parak, J., & Korhonen, I. (2014). Chapter 2.3 - Application of Optical Heart Rate Monitoring. In E. Sazonov & M. R. Neuman (Eds.), *Wearable Sensors* (pp. 105–129). Academic Press.

280. Gillinov, S., Etiwy, M., Wang, R., Blackburn, G., Phelan, D., Gillinov, A., Houghtaling, P., Javadikasgari, H., & Desai, M. (2017). Variable Accuracy of Wearable Heart Rate Monitors during Aerobic Exercise. *Medicine & Science in Sports & Exercise*, *49*, 1.

281. Mendes, M. de A., da Silva, I., Ramires, V., Reichert, F., Martins, R., Ferreira, R., & Tomasi, E. (2018). Metabolic equivalent of task (METs) thresholds as an indicator of physical activity intensity. *PLoS ONE*, *13*(7), e0200701.

282. Watson, K. B., Carlson, S. A., Carroll, D. D., & Fulton, J. E. (2014). Comparison of accelerometer cut points to estimate physical activity in US adults. *Journal of Sports Sciences*, *32*(7), 660–669.

283. Evenson, K. R., Catellier, D. J., Gill, K., Ondrak, K. S., & McMurray, R. G. (2008). Calibration of two objective measures of physical activity for children. *Journal of Sports Sciences*, *26*(14), 1557–1565.

284. Rowlands, A. v., Yates, T., Davies, M., Khunti, K., & Edwardson, C. l. (2016). Raw Accelerometer Data Analysis with GGIR R-package. *Medicine & Science in Sports & Exercise*, *48*(10), 1935–1941.

285. Da silva, I. C. M., Van hees, V. T., Ramires, V. V., Knuth, A. G., Bielemann, R. M., Ekelund, U., Brage, S., & Hallal, P. C. (2014). Physical activity levels in three Brazilian birth cohorts as assessed with raw triaxial wrist accelerometry. *International Journal of Epidemiology*, *43*(6), 1959–1968.

286. R Core Team. (2020). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. http://www.r-project.org/

287. van Hees, V. T., Gorzelniak, L., Dean León, E. C., Eder, M., Pias, M., Taherian, S., Ekelund, U., Renström, F., Franks, P. W., Horsch, A., & Brage, S. (2013). Separating Movement and Gravity Components in an Acceleration Signal and Implications for the Assessment of Human Daily Physical Activity. *PLoS ONE*, *8*(4), e61691.

288. Migueles, J. H., Rowlands, A. V., Huber, F., Sabia, S., & van Hees, V. T. (2019). GGIR: A Research Community–Driven Open Source R Package for Generating Physical Activity and Sleep Outcomes From Multi-Day Raw Accelerometer Data. *Journal for the Measurement of Physical Behaviour*, *2*(3), 188–196.

289. Kontostoli, E., Jones, A. P., Pearson, N., Foley, L., Biddle, S. J. H., & Atkin, A. J. (2022). The Association of Contemporary Screen Behaviours with Physical Activity, Sedentary Behaviour and Sleep in Adolescents: a Cross-sectional Analysis of the Millennium Cohort Study. *International Journal of Behavioral Medicine*.

290. van Hees, V. T., Sabia, S., Jones, S. E., Wood, A. R., Anderson, K. N., Kivimäki, M., Frayling, T. M., Pack, A. I., Bucan, M., Trenell, M. I., Mazzotti, D. R., Gehrman, P. R., Singh-Manoux, B. A., & Weedon, M. N. (2018). Estimating sleep parameters using an accelerometer without sleep diary. *Scientific Reports*, *8*(1).

291. *Fit Got Real - This Girl Can*. (n.d.). Retrieved 5 September 2019, from http://www.thisgirlcan.co.uk/

292. Camacho-Miñano, M. J., LaVoi, N. M., & Barr-Anderson, D. J. (2011). Interventions to promote physical activity among young and adolescent girls: a systematic review. *Health Education Research*, *26*(6), 1025–1049.

293. Corder, K., Sharp, S. J., Atkin, A. J., Andersen, L. B., Cardon, G., Page, A., Davey, R., Grøntved, A., Hallal, P. C., Janz, K. F., Kordas, K., Kriemler, S., Puder, J. J., Sardinha, L. B., Ekelund, U., van Sluijs, E. M. F., Cardon, G., Cooper, A., Puder, J. J., … Timperio, A. (2016). Age-related patterns of vigorous-intensity physical activity in youth: The International Children’s Accelerometry Database. *Preventive Medicine Reports*, *4*, 17–22.

294. Dias, K. I., White, J., Jago, R., Cardon, G., Davey, R., Janz, K. F., Pate, R. R., Puder, J. J., Reilly, J. J., & Kipping, R. (2019). International Comparison of the Levels and Potential Correlates of Objectively Measured Sedentary Time and Physical Activity among Three-to-Four-Year-Old Children. *International Journal of Environmental Research and Public Health 2019, Vol. 16, Page 1929*, *16*(11), 1929.

295. Van Ekris, E., Wijndaele, K., Altenburg, T. M., Atkin, A. J., Twisk, J., Andersen, L. B., Janz, K. F., Froberg, K., Northstone, K., Page, A. S., Sardinha, L. B., Van Sluijs, E. M. F., Chinapaw, M., Andersen, L. B., Anderssen, S., Atkin, A. J., Cardon, G., Davey, R., Ekelund, U., … Van Sluijs, E. M. F. (2020). Tracking of total sedentary time and sedentary patterns in youth: A pooled analysis using the International Children’s Accelerometry Database (ICAD). *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 1–10.

296. Kwon, S., Janz, K. F., Cooper, A., Ekelund, U., Esliger, D., Griew, P., Judge, K., Ness, A., Riddoch, C., Salmon, J., & Sherar, L. (2012). Tracking of accelerometry-measured physical activity during childhood: ICAD pooled analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 1–8.

297. Tarp, J., Child, A., White, T., Westgate, K., Bugge, A., Grøntved, A., Wedderkopp, N., Andersen, L. B., Cardon, G., Davey, R., Janz, K. F., Kriemler, S., Northstone,

K., Page, A. S., Puder, J. J., Reilly, J. J., Sardinha, L. B., van Sluijs, E. M. F., Ekelund, U., … Brage, S. (2018). Physical activity intensity, bout-duration, and cardiometabolic risk markers in children and adolescents. *International Journal of Obesity 2018 42:9*, *42*(9), 1639–1650.

298. Ackah, M., Owiredu, D., Salifu, M. G., & Yeboah, C. O. (2022). Estimated prevalence and gender disparity of physical activity among 64,127 in-school adolescents (aged 12–17 years): A multi-country analysis of Global School-based Health Surveys from 23 African countries. *PLOS Global Public Health*, *2*(10), e0001016.
299. Sherar, L. B., Griffin, T. P., Ekelund, U., Cooper, A. R., Esliger, D. W., van Sluijs, E. M. F., Andersen, L. B., Cardon, G., Davey, R., Froberg, K., Hallal, P. C., Janz, K. F., Kordas, K., Kriemler, S., Pate, R. R., Puder, J. J., Sardinha, L. B., Timperio, A. F., & Page, A. S. (2016). Association between maternal education and objectively measured physical activity and sedentary time in adolescents. *J Epidemiol Community Health*, *70*(6), 541–548.
300. Evenson, K. R., Catellier, D. J., Gill, K., Ondrak, K. S., & McMurray, R. G. (2008). Calibration of two objective measures of physical activity for children. *Journal of Sports Sciences*, *26*(14), 1557–1565.
301. Kwon, S., Andersen, L. B., Grøntved, A., Kolle, E., Cardon, G., Davey, R., Kriemler, S., Northstone, K., Page, A. S., Puder, J. J., Reilly, J. J., Sardinha, L. B., Van Sluijs, E. M. F., & Janz, K. F. (2019). A closer look at the relationship among accelerometer-based physical activity metrics: ICAD pooled data. *International Journal of Behavioral Nutrition and Physical Activity*, *16*(1), 1–9.
302. Brockman, R., Jago, R., & Fox, K. R. (2010). The contribution of active play to the physical activity of primary school children. *Preventive Medicine*, *51*(2), 144–147.

303. Nilsson, A., Bo Andersen, L., Ommundsen, Y., Froberg, K., Sardinha, L. B., Piehl-Aulin, K., & Ekelund, U. (2009). Correlates of objectively assessed physical activity and sedentary time in children: A cross-sectional study (The European youth heart study). *BMC Public Health*, *9*(1), 1–7.

304. Maher, C. A., & Olds, T. S. (2011). Minutes, MET minutes, and METs: unpacking socio-economic gradients in physical activity in adolescents. *Journal of Epidemiology & Community Health*, *65*(2), 160–165.

305. Mooses, K., & Kull, M. (2019). The participation in organised sport doubles the odds of meeting physical activity recommendations in 7–12-year-old children. *Https://Doi.Org/10.1080/17461391.2019.1645887*, *20*(4), 563–569.

306. Varma, V. R., Dey, D., Leroux, A., Di, J., Urbanek, J., Xiao, L., & Zipunnikov, V. (2017). Re-evaluating the effect of age on physical activity over the lifespan. *Preventive Medicine*, *101*, 102–108.

307. Norris, T., Seaton, S. E., Manktelow, B. N., Baker, P. N., Kurinczuk, J. J., Field, D., Draper, E. S., & Smith, L. K. (2018). Updated birth weight centiles for England and Wales. *Archives of Disease in Childhood - Fetal and Neonatal Edition*, *103*(6), F577–F582.

308. Cheng, Y., Liu, M., Liu, Y., Xu, H., Chen, X., Zheng, H., Wu, X., Shen, Z., & Shen, C. (2021). Chronic kidney disease: prevalence and association with handgrip strength in a cross-sectional study. *BMC Nephrology*, *22*(1), 1–8.

309. Zbořilová, V., Přidalová, M., & Kaplanová, T. (2021). Body Fat Mass, Percent Body Fat, Fat-Free Mass, and Skeletal Muscle Mass Reference Curves for Czech Children Aged 6–11 Years. *Children 2021, Vol. 8, Page 366*, *8*(5), 366.

310. Albrecht, B. M., Stalling, I., & Bammann, K. (2021). Sex- and age-specific normative values for handgrip strength and components of the Senior Fitness Test

in community-dwelling older adults aged 65–75 years in Germany: results from the OUTDOOR ACTIVE study. *BMC Geriatrics*, *21*(1), 1–8.

311. Hepp, T., Schmid, M., & Mayr, A. (2019). Significance Tests for Boosted Location and Scale Models with Linear Base-Learners. *International Journal of Biostatistics*, *15*(1).

312. Atkin, A. J., Biddle, S. J. H., Broyles, S. T., Chinapaw, M., Ekelund, U., Esliger, D. W., Hansen, B. H., Kriemler, S., Puder, J. J., Sherar, L. B., van Sluijs, E. M. F., Andersen, L. B., Anderssen, S., Cardon, G., Davey, R., Hallal, P., Janz, K. F., Møller, N., Molloy, L., … Timperio, A. (2017). Harmonising data on the correlates of physical activity and sedentary behaviour in young people: Methods and lessons learnt from the international Children's Accelerometry database (ICAD). *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 1–12.

313. Pate, R. R., Almeida, M. J., McIver, K. L., Pfeiffer, K. A., & Dowda, M. (2006). Validation and Calibration of an Accelerometer in Preschool Children. *Obesity*, *14*(11), 2000–2006.

314. Fraser, A., Macdonald-Wallis, C., Tilling, K., Boyd, A., Golding, J., Smith, G. D., Henderson, J., Macleod, J., Molloy, L., Ness, A., Ring, S., Nelson, S. M., & Lawlor, D. A. (2012). Cohort Profile: The Avon Longitudinal Study of Parents and Children: ALSPAC mothers cohort Downloaded from. *International Journal of Epidemiology*, 1–14.

315. Mitchell, J. A., Pate, R. R., Beets, M. W., & Nader, P. R. (2013). Time spent in sedentary behavior and changes in childhood BMI: A longitudinal study from ages 9 to 15 years. *International Journal of Obesity*, *37*(1), 54–60.

316. Jiménez-Pav́n, D., Kelly, J., & Reilly, J. J. (2010). Associations between objectively measured habitual physical activity and adiposity in children and adolescents: Systematic review. *International Journal of Pediatric Obesity*, *5*(1), 3–18.

317. Hands, B. P., Chivers, P. T., Parker, H. E., Beilin, L., Kendall, G., & Larkin, D. (2011). The associations between physical activity, screen time and weight from 6 to 14 yrs: The Raine Study. *Journal of Science and Medicine in Sport*, *14*(5), 397–403.

318. Richmond, R. C., Davey Smith, G., Ness, A. R., den Hoed, M., McMahon, G., & Timpson, N. J. (2014). Assessing Causality in the Association between Child Adiposity and Physical Activity Levels: A Mendelian Randomization Analysis. *PLOS Medicine*, *11*(3), e1001618.

319. Must, A., & Anderson, S. E. (2006). Body mass index in children and adolescents: considerations for population-based applications. *International Journal of Obesity*, *30*(4), 590–594.

320. Aarø, L. E., Flisher, A. J., Kaaya, S., Onya, H., Namisi, F. S., & Wubs, A. (2009). Parental education as an indicator of socioeconomic status: Improving quality of data by requiring consistency across measurement occasions. *Scandinavian Journal of Public Health*, *37*(2_suppl), 16–27.

321. Stalsberg, R., & Pedersen, A. V. (2018). Are differences in physical activity across socioeconomic groups associated with choice of physical activity variables to report? *International Journal of Environmental Research and Public Health*, *15*(5).

322. McNeill, L. H., Kreuter, M. W., & Subramanian, S. V. (2006). Social Environment and Physical activity: A review of concepts and evidence. *Social Science and Medicine*, *63*(4), 1011–1022.

323. Somerset, S., & Hoare, D. J. (2018). Barriers to voluntary participation in sport for children: a systematic review. *BMC Pediatrics*, *18*(1), 47.

324. Rigby, R. A., Stasinopoulos, D. M., & Lane, P. W. (2005). Generalized additive models for location, scale and shape. *Journal of the Royal Statistical Society: Series C (Applied Statistics)*, *54*(3), 507–554.

325. Hildebrand, M., Kolle, E., Hansen, B. H., Collings, P. J., Wijndaele, K., Kordas, K., Cooper, A. R., Sherar, L. B., Andersen, L. B., Sardinha, L. B., Kriemler, S., Hallal, P., Van Sluijs, E., & Ekelund, U. (2015). Association between birth weight and objectively measured sedentary time is mediated by central adiposity: data in 10,793 youth from the International Children's Accelerometry Database. *The American Journal of Clinical Nutrition*, *101*(5), 983–990.

326. Hansen, B. H., Anderssen, S. A., Andersen, L. B., Hildebrand, M., Kolle, E., Steene-Johannessen, J., Kriemler, S., Page, A. S., Puder, J. J., Reilly, J. J., Sardinha, L. B., van Sluijs, E. M. F., Wedderkopp, N., Ekelund, U., Andersen, L. B., Anderssen, S. A., Atkin, A. J., Davey, R., Esliger, D. W., … Timperio, A. (2018). Cross-Sectional Associations of Reallocating Time Between Sedentary and Active Behaviours on Cardiometabolic Risk Factors in Young People: An International Children's Accelerometry Database (ICAD) Analysis. *Sports Medicine*, *48*(10), 2401–2412.

327. Rich, C., Griffiths, L. J., & Dezateux, C. (2012). Seasonal variation in accelerometer-determined sedentary behaviour and physical activity in children: a review. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 1–8.

328. Harrison, F., Goodman, A., van Sluijs, E. M. F., Andersen, L. B., Cardon, G., Davey, R., Janz, K. F., Kriemler, S., Molloy, L., Page, A. S., Pate, R., Puder, J. J., Sardinha, L. B., Timperio, A., Wedderkopp, N., Jones, A. P., Anderssen, S., Cardon, G., Cooper, A., … van Sluijs, E. M. F. (2017). Weather and children's

physical activity; How and why do relationships vary between countries? *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 1–13.

329. Cole, T. J., Freeman, J. V., & Preece, M. A. (1995). Body mass index reference curves for the UK, 1990. *Archives of Disease in Childhood*, *73*(1), 25–29.
330. Robinson, T. N. (2010). Chapter 25 - Stealth Interventions for Obesity Prevention and Control: Motivating Behavior Change. In L. Dubé, A. Bechara, A. Dagher, A. Drewnowski, J. Lebel, P. James, & R. Y. Yada (Eds.), *Obesity Prevention* (pp. 319–327). Academic Press.
331. Chalabaev, A., Sarrazin, P., Fontayne, P., Boiché, J., & Clément-Guillotin, C. (2012). *The influence of sex stereotypes and gender roles on participation and performance in sport and exercise: Review and future directions*.
332. Sterdt, E., Liersch, S., & Walter, U. (2013). Correlates of physical activity of children and adolescents: A systematic review of reviews: *Http://Dx.Doi.Org/10.1177/0017896912469578*, *73*(1), 72–89.
333. Watson, A., Eliott, J., & Mehta, K. (2015). Perceived barriers and facilitators to participation in physical activity during the school lunch break for girls aged 12–13 years: *Http://Dx.Doi.Org/10.1177/1356336X14567545*, *21*(2), 257–271.
334. Hawkins, M. S., Storti, K. L., Richardson, C. R., King, W. C., Strath, S. J., Holleman, R. G., & Kriska, A. M. (2009). Objectively measured physical activity of USA adults by sex, age, and racial/ethnic groups: a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*, *6*(1), 1–7.
335. *Microdata: National Health Survey, 2020–21*. (2023). Australian Bureau of Statistics. https://www.aihw.gov.au/reports/australias-health/insufficient-physical-activity
336. Lindsay, T., Westgate, K., Wijndaele, K., Hollidge, S., Kerrison, N., Forouhi, N., Griffin, S., Wareham, N., & Brage, S. (2019). Descriptive epidemiology of

physical activity energy expenditure in UK adults (The Fenland study). *International Journal of Behavioral Nutrition and Physical Activity*, *16*(1), 126.

337. Hansen, B. H., Kolle, E., Steene-Johannessen, J., Dalene, K. E., Ekelund, U., & Anderssen, S. A. (2019). Monitoring population levels of physical activity and sedentary time in Norway across the lifespan. *Scandinavian Journal of Medicine & Science in Sports*, *29*(1), 105–112.
338. Baptista, F., Santos, D. A., Silva, A. M., Mota, J., Santos, R., Vale, S., Ferreira, J. P., Raimundo, A. M., Moreira, H., & Sardinha, L. B. (2012). Prevalence of the Portuguese Population Attaining Sufficient Physical Activity. *Medicine & Science in Sports & Exercise*, *44*(3), 466–473.
339. Aebi, N. J., Bringolf-Isler, B., Schaffner, E., Caviezel, S., Imboden, M., & Probst-Hensch, N. (2020). Patterns of cross-sectional and predictive physical activity in Swiss adults aged 52+: results from the SAPALDIA cohort. *Swiss Medical Weekly*, *150*(2526), w20266–w20266.
340. Parker, K. (2013, March 14). Modern Parenthood. *Pew Research Center's Social & Demographic Trends Project*. https://www.pewresearch.org/social-trends/2013/03/14/modern-parenthood-roles-of-moms-and-dads-converge-as-they-balance-work-and-family/
341. Madsen, K. A., McCulloch, C. E., & Crawford, P. B. (2009). Parent Modeling: Perceptions of Parents' Physical Activity Predict Girls' Activity throughout Adolescence. *The Journal of Pediatrics*, *154*(2), 278-283.e2.
342. *World Economic Outlook: Countering the Cost-of-Living Crisis.* (2022). International Monetary Fund. https://www.imf.org/en/Publications/WEO/weo-database/2022/October/weo-report
343. *Statistical Yearbook of Portugal 2002*. (2003). Instituto Nacional De Estatistica.

344. Robertson, W., Stewart-Brown, S., Wilcock, E., Oldfield, M., & Thorogood, M. (2011). Utility of Accelerometers to Measure Physical Activity in Children Attending an Obesity Treatment Intervention. *Journal of Obesity*, *2011*, 398918.

345. Ottevaere, C., Huybrechts, I., De Meester, F., De Bourdeaudhuij, I., Cuenca-Garcia, M., & De Henauw, S. (2011). The use of accelerometry in adolescents and its implementation with non-wear time activity diaries in free-living conditions. *Journal of Sports Sciences*, *29*(1), 103–113.

346. King, A. C., Parkinson, K. N., Adamson, A. J., Murray, L., Besson, H., Reilly, J. J., & Basterfield, L. (2011). Correlates of objectively measured physical activity and sedentary behaviour in English children. *European Journal of Public Health*, *21*(4), 424–431.

347. van Tuyckom, C., Scheerder, J., & Bracke, P. (2010). Gender and age inequalities in regular sports participation: A cross-national study of 25 European countries. *Https://Doi.Org/10.1080/02640414.2010.492229*, *28*(10), 1077–1084.

348. Chaput, J.-P., Barnes, J. D., Tremblay, M. S., Fogelholm, M., Hu, G., Lambert, E. V., Maher, C., Maia, J., Olds, T., Onywera, V., Sarmiento, O. L., Standage, M., Tudor-Locke, C., & Katzmarzyk, P. T. (2018). Inequality in physical activity, sedentary behaviour, sleep duration and risk of obesity in children: a 12-country study. *Obesity Science & Practice*, *4*(3), 229–237.

349. Lu, W., McKyer, E. L. J., Lee, C., Ory, M. G., Goodson, P., & Wang, S. (2015). Children’s active commuting to school: An interplay of self-efficacy, social economic disadvantage, and environmental characteristics. *International Journal of Behavioral Nutrition and Physical Activity*, *12*(1), 1–14.

350. González, S. A., Aubert, S., Barnes, J. D., Larouche, R., & Tremblay, M. S. (2020). Profiles of Active Transportation among Children and Adolescents in the Global

Matrix 3.0 Initiative: A 49-Country Comparison. *International Journal of Environmental Research and Public Health*, *17*(16), 1–29.

351. Aadland, E., Okely, A. D., Kristine, A., & Nilsen, O. (2022). Trajectories of physical activity and sedentary time in Norwegian children aged 3–9 years: a 5-year longitudinal study. *International Journal of Behavioral Nutrition and Physical Activity 2022 19:1*, *19*(1), 1–13.

352. Mygind, E. (2022). Udeskole—Pupils' Physical Activity and Gender Perspectives. In R. Jucker & J. von Au (Eds.), *High-Quality Outdoor Learning: Evidence-based Education Outside the Classroom for Children, Teachers and Society* (pp. 135–152). Springer International Publishing.

353. Mygind, E. (2016). Physical Activity during Learning Inside and Outside the Classroom. *Health Behavior and Policy Review*, *3*(5), 455–467.

354. Kek, C. C., García Bengoechea, E., Spence, J. C., & Mandic, S. (2019). The relationship between transport-to-school habits and physical activity in a sample of New Zealand adolescents. *Journal of Sport and Health Science*, *8*(5), 463–470.

355. Pate, R. R., Flynn, J. I., & Dowda, M. (2016). Policies for promotion of physical activity and prevention of obesity in adolescence. *Journal of Exercise Science & Fitness*, *14*(2), 47–53.

356. Pouliou, T., Sera, F., Griffiths, L., Joshi, H., Geraci, M., Cortina-Borja, M., & Law, C. (2015). Environmental influences on children's physical activity. *Journal of Epidemiology and Community Health*, *69*(1), 77–85.

357. Rowlands, A. v., Edwardson, C. l., Davies, M. j., Khunti, K., Harrington, D. m., & Yates, T. (2018). Beyond Cut Points: Accelerometer Metrics that Capture the Physical Activity Profile. *Medicine & Science in Sports & Exercise*, *50*(6), 1323–1332.

358. Green, M. (2007). Olympic glory or grassroots development?: Sport policy priorities in Australia, Canada and the United Kingdom, 1960 – 2006. *The International Journal of the History of Sport*, *24*(7), 921–953.

359. Aspen Institute. (2021). *A Playbook to Develop Every Student Through Sports*.

360. Aira, T., Salin, K., Vasankari, T., Korpelainen, R., Parkkari, J., Heinonen, O. J., Savonen, K., Alanko, L., Kannas, L., Selänne, H., Villberg, J., Vähä-Ypyä, H., & Kokko, S. (2019). Training Volume and Intensity of Physical Activity among Young Athletes: The Health Promoting Sports Club (HPSC) Study. *Advances in Physical Education*, *9*(4), 270–287.

361. Freeman, J. V., Cole, T. J., Chinn, S., Jones, P. R., White, E. M., & Preece, M. A. (1995). Cross sectional stature and weight reference curves for the UK, 1990. *Archives of Disease in Childhood*, *73*(1), 17–24.

362. Golding, G., Pembrey, P., & Jones, J. (2001). ALSPAC–The Avon Longitudinal Study of Parents and Children. *Paediatric and Perinatal Epidemiology*, *15*(1), 74–87.

363. Nielsen, G., Grønfeldt, V., Toftegaard-Støckel, J., & Andersen, L. B. (2011). Predisposed to participate? The influence of family socio-economic background on children’s sports participation and daily amount of physical activity. *Http://Dx.Doi.Org/10.1080/03031853.2011.625271*, *15*(1), 1–27.

364. Wen, M., Zhang, X., Harris, C. D., Holt, J. B., & Croft, J. B. (2013). Spatial Disparities in the Distribution of Parks and Green Spaces in the USA. *Annals of Behavioral Medicine : A Publication of the Society of Behavioral Medicine*, *45*(Suppl 1), 18.

365. Boone-Heinonen, J., Casanova, K., Richardson, A. S., & Gordon-Larsen, P. (2010). Where can they play? Outdoor spaces and physical activity among adolescents in U.S. urbanized areas. *Preventive Medicine*, *51*(3–4), 295–298.

366. Kontou, E., McDonald, N. C., Brookshire, K., Pullen-Seufert, N. C., & LaJeunesse, S. (2020). U.S. active school travel in 2017: Prevalence and correlates. *Preventive Medicine Reports*, *17*, 101024.

367. Sallis, J. F., Conway, T. L., Cain, K. L., Carlson, J. A., Frank, L. D., Kerr, J., Glanz, K., Chapman, J. E., & Saelens, B. E. (2018). Neighborhood built environment and socioeconomic status in relation to physical activity, sedentary behavior, and weight status of adolescents. *Preventive Medicine*, *110*, 47.

368. UNESCO. (2014). *World-wide survey of school physical education: final report*. https://unesdoc.unesco.org/in/documentViewer.xhtml?v=2.1.196&id=p::usmarcdef_0000229335&file=/in/rest/annotationSVC/DownloadWatermarkedAttachment/attach_import_a1f0f57a-769f-427e-9ba8-0c96e81d3016%3F_%3D229335eng.pdf&locale=en&multi=true&ark=/ark:/48223/pf0000229335/PDF/229335eng.pdf#3663_13_SHS_Physical%20Education_inside%20E%20141106.indd%3A.27846%3A1285

369. Reichert, F. F., Menezes, A. M. B., Wells, J. C. K., Ekelund, U., Rodrigues, F. M., & Hallal, P. C. (2009). A methodological model for collecting high-quality data on physical activity in developing settings-the experience of the 1993 Pelotas (Brazil) Birth Cohort study. *Journal of Physical Activity & Health*, *6*(3), 360–366.

370. Goyder, J. (1987). *The Silent Minority: Non-respondents In Sample Surveys*. Routledge.

371. Biddle, S. J. H., Atkin, A. J., Cavill, N., & Foster, C. (2011). Correlates of physical activity in youth: a review of quantitative systematic reviews. *International Review of Sport and Exercise Psychology*, *4*(1), 25–49.

372. Eyre, E. L. J., Duncan, M. J., Birch, S. L., & Cox, V. M. (2014). Low socio-economic environmental determinants of children's physical activity in Coventry, UK: A Qualitative study in parents. *Preventive Medicine Reports*, *1*, 32–42.

373. Christensen, D. L., Alcalá-Sánchez, I., Leal-Berumen, I., Conchas-Ramirez, M., & Brage, S. (2012). Physical activity, cardio-respiratory fitness, and metabolic traits in rural mexican tarahumara. *American Journal of Human Biology*, *24*(4), 558–561.

374. UNICEF. (2020). *Worlds of Influence: Understanding what shapes child well-being in rich countries*. https://www.unicef-irc.org/child-well-being-report-card-16

375. Bennett, J. E., Stevens, G. A., Mathers, C. D., Bonita, R., Rehm, J., Kruk, M. E., Riley, L. M., Dain, K., Kengne, A. P., Chalkidou, K., Beagley, J., Kishore, S. P., Chen, W., Saxena, S., Bettcher, D. W., Grove, J. T., Beaglehole, R., & Ezzati, M. (2018). NCD Countdown 2030: worldwide trends in non-communicable disease mortality and progress towards Sustainable Development Goal target 3.4. *The Lancet*, *392*(10152), 1072–1088.

376. Lagravinese, R., Liberati, P., & Resce, G. (2020). Measuring Health Inequality in US: A Composite Index Approach. *Social Indicators Research*, *147*(3), 921–946.

377. Commission on Social Determinants of Health. (2008). Closing the gap in a generation : health equity through action on the social determinants of health : final report of the commission on social determinants of health. *Combler Le Fossé En Une Génération : Instaurer l'équité En Santé En Agissant Sur Les Déterminants Sociaux de La Santé : Rapport Final de La Commission Des Déterminants Sociaux de La Santé*, 247.

378. Wilkins, R., Vera-Toscano, E., Botha, F., & Dahmann, S. C. (2021). *The Household, Income and Labour Dynamics in Australia Survey: Selected Findings from Waves 1 to 19*.

379. Reilly, J. J. (2016). When does it all go wrong? Longitudinal studies of changes in moderate-to-vigorous-intensity physical activity across childhood and adolescence. *Journal of Exercise Science & Fitness*, *14*(1), 1–6.

380. Farooq, A., Martin, A., Janssen, X., Wilson, M. G., Gibson, A. M., Hughes, A., & Reilly, J. J. (2020). Longitudinal changes in moderate-to-vigorous-intensity physical activity in children and adolescents: A systematic review and meta-analysis. *Obesity Reviews*, *21*(1), e12953.

381. Owen, N., Sparling, P. B., Healy, G. N., Dunstan, D. W., & Matthews, C. E. (2010). Sedentary behavior: Emerging evidence for a new health risk. *Mayo Clinic Proceedings*, *85*(12), 1138–1141.

382. Lummaa, V. (2003). Early Developmental conditions and reproductive success in humans: Downstream effects of prenatal famine, birthweight, and timing of birth. *American Journal of Human Biology*, *15*(3), 370–379.

383. Pollom, T. R., Cross, C. L., Herlosky, K. N., Ford, E., & Crittenden, A. N. (2021). Effects of a mixed-subsistence diet on the growth of Hadza children. *American Journal of Human Biology*, *33*(1), e23455.

384. Power, M. L. (2012). The human obesity epidemic, the mismatch paradigm, and our modern "captive" environment. *American Journal of Human Biology*, *24*(2), 116–122.

385. Wells, J. C. K. (2006). The evolution of human fatness and susceptibility to obesity: an ethological approach. *Biological Reviews*, *81*(02), 183.

386. Bender, R., Jöckel, K. H., Trautner, C., Spraul, M., & Berger, M. (1999). Effect of age on excess mortality in obesity. *Journal of the American Medical Association*, *281*(16), 1498–1504.

387. Boutari, C., Pappas, P. D., Mintziori, G., Nigdelis, M. P., Athanasiadis, L., Goulis, D. G., & Mantzoros, C. S. (2020). The effect of underweight on female and male reproduction. *Metabolism: Clinical and Experimental*, *107*, 154229.

388. Amiri, M., & Tehrani, F. R. (2020). Potential Adverse Effects of Female and Male Obesity on Fertility: A Narrative Review. *International Journal of Endocrinology and Metabolism*, *18*(3), 101776.

389. Franklin, B. A., Thompson, P. D., Al-Zaiti, S. S., Albert, C. M., Hivert, M.-F., Levine, B. D., Lobelo, F., Madan, K., Sharrief, A. Z., Eijsvogels, T. M. H., & null, null. (2020). Exercise-Related Acute Cardiovascular Events and Potential Deleterious Adaptations Following Long-Term Exercise Training: Placing the Risks Into Perspective–An Update: A Scientific Statement From the American Heart Association. *Circulation*, *141*(13), e705–e736.

390. Hart, B. L. (1988). Biological basis of the behavior of sick animals. *Neuroscience and Biobehavioral Reviews*, *12*(2), 123–137.

391. Fleg, J. L., Morrell, C. H., Bos, A. G., Brant, L. J., Talbot, L. A., Wright, J. G., & Lakatta, E. G. (2005). Accelerated Longitudinal Decline of Aerobic Capacity in Healthy Older Adults. *Circulation*, *112*(5), 674–682.

392. Milanović, Z., Pantelić, S., Trajković, N., Sporiš, G., Kostić, R., & James, N. (2013). Age-related decrease in physical activity and functional fitness among elderly men and women. *Clinical Interventions in Aging*, *8*, 549–556.

393. Yamauchi, T., Sato, H., & Kawamura, K. (2000). Nutritional Status, Activity Pattern, And Dietary Intake Among The Baka Hunter-Gatherers In The Village Camps In Cameroon. *African Study Monographs*, *21*(2), 67–82.

394. Ojiambo, R., Gibson, A. R., Konstabel, K., Lieberman, D. E., Speakman, J. R., Reilly, J. J., & Pitsiladis, Y. P. (2013). Free-living physical activity and energy expenditure of rural children and adolescents in the Nandi region of Kenya. *Annals of Human Biology*, *40*(4), 318–323.

395. Diaz, K. M., Duran, A. T., Colabianchi, N., Judd, S. E., Howard, V. J., & Hooker, S. P. (2019). Potential effects on mortality of replacing sedentary time with short

sedentary bouts or physical activity: A national cohort study. *American Journal of Epidemiology*, *188*(3), 537–544.

396. Wood, B. M., Harris, J. A., Raichlen, D. A., Pontzer, H., Sayre, K., Sancilio, A., Berbesque, C., Crittenden, A. N., Mabulla, A., McElreath, R., Cashdan, E., & Jones, J. H. (2021). Gendered movement ecology and landscape use in Hadza hunter-gatherers. *Nature Human Behaviour*, 1–11.
397. Samson, D. R., Crittenden, A. N., Mabulla, I. A., Mabulla, A. Z. P., & Nunn, C. L. (2017). Hadza sleep biology: Evidence for flexible sleep-wake patterns in hunter-gatherers. *American Journal of Physical Anthropology*, *162*(3), 573–582.
398. Katzmarzyk, P., Leonard, W., Crawford, M., & Sukernik, R. (1994). Resting metabolic rate and daily energy expenditure among two indigenous Siberian populations. *American Journal of Human Biology*, *6*(6), 719–730.
399. Kashiwazaki, H., Dejima, Y., Orias-Rivera, J., & Coward, W. A. (1995). Energy expenditure determined by the doubly labeled water method in Bolivian Aymara living in a high altitude agropastoral community. *American Journal of Clinical Nutrition*, *62*(5), 901–910.
400. Lewis, J. (2002). *FOREST HUNTER-GATHERERS AND THEIR WORLD: A Study of the Mbendjele Yaka Pygmies of Congo-Brazzaville and Their Secular and Religious Activities and Representations*. UCL.
401. Christensen, D. L., Faurholt-Jepsen, D., Boit, M. K., Mwaniki, D. L., Kilonzo, B., Tetens, I., Kiplamai, F. K., Cheruiyot, S. C., Friis, H., Borch-Johnsen, K., Wareham, N. J., & Brage, S. (2012). Cardiorespiratory fitness and physical activity in Luo, Kamba, and Maasai of rural Kenya. *American Journal of Human Biology*, *24*(6), 723–729.

402. Kaplan, H. S., & Robson, A. J. (2002). The emergence of humans: The coevolution of intelligence and longevity with intergenerational transfers. *Proceedings of the National Academy of Sciences*, *99*(15), 10221–10226.

403. Kaplan, H., Hill, K., Lancaster, J., & Hurtado, A. M. (2000). A theory of human life history evolution: Diet, intelligence, and longevity. *Evolutionary Anthropology: Issues, News, and Reviews*, *9*(4), 156–185.

404. Sear, R., & Mace, R. (2008). Who keeps children alive? A review of the effects of kin on child survival. *Evolution and Human Behavior*, *29*(1), 1–18.

405. Meehan, C. L., Quinlan, R., & Malcom, C. D. (2013). Cooperative breeding and maternal energy expenditure among aka foragers. *American Journal of Human Biology*, *25*(1), 42–57.

406. Page, A. E., Emmott, E. H., Dyble, M., Smith, D., Chaudhary, N., Viguier, S., & Migliano, A. B. (2021). Children are important too: juvenile playgroups and maternal childcare in a foraging population, the Agta. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *376*(1827), rstb.2020.0026.

407. Savard, C., Lebrun, A., O’Connor, S., Fontaine-Bisson, B., Haman, F., & Morisset, A.-S. (2021). Energy expenditure during pregnancy: a systematic review. *Nutrition Reviews*, *79*(4), 394–409.

408. Prentice, A. (1988). Energy Costs Of Lactation. *Annual Review of Nutrition*, *8*(1), 63–79.

409. Valeggia, C., & Ellison, P. T. (2009). Interactions between metabolic and reproductive functions in the resumption of postpartum fecundity. *American Journal of Human Biology*, *21*(4), 559–566.

410. Poudevigne, M. S., & O’Connor, P. J. (2006). A review of physical activity patterns in pregnant women and their relationship to psychological health. *Sports Medicine*, *36*(1), 19–38.

411. Urlacher, S. S., & Kramer, K. L. (2018). Evidence for energetic tradeoffs between physical activity and childhood growth across the nutritional transition OPEN. *Scientific RepoRts* |, *8*, 369.

412. Vanhelst, J., Béghin, L., Duhamel, A., Bergman, P., Sjöström, M., & Gottrand, F. (2012). Comparison of uniaxial and triaxial accelerometry in the assessment of physical activity among adolescents under free-living conditions: The HELENA study. *BMC Medical Research Methodology*, *12*(1), 26.

413. Hildebrand, M., Van Hees, V. T., Hansen, B. H., & Ekelund, U. (2014). Age Group Comparability of Raw Accelerometer Output from Wrist- and Hip-Worn Monitors. *Medicine & Science in Sports & Exercise*, *46*(9), 1816–1824.

414. Ramirez Rozzi, F. V. (2018). Reproduction in the Baka pygmies and drop in their fertility with the arrival of alcohol. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(27), E6126–E6134.

415. Doherty, A., Jackson, D., Hammerla, N., Plötz, T., Olivier, P., Granat, M. H., White, T., Van Hees, V. T., Trenell, M. I., Owen, C. G., Preece, S. J., Gillions, R., Sheard, S., Peakman, T., Brage, S., & Wareham, N. J. (2017). Large scale population assessment of physical activity using wrist worn accelerometers: The UK biobank study. *PLoS ONE*, *12*(2).

416. Franssen, W., Vanbrabant, E., Cuveele, E., Ivanova, A., Franssen, G. H. L. M., & Eijnde, B. O. (2021). Sedentary behaviour, physical activity and cardiometabolic health in highly trained athletes: A systematic review and meta-analysis. *Https://Doi.Org/10.1080/17461391.2021.1955013*, 1–33.

417. STILES, V. H., PEARCE, M., MOORE, I. S., LANGFORD, J., & ROWLANDS, A. V. (2018). Wrist-worn Accelerometry for Runners: Objective Quantification of Training Load. *Medicine and Science in Sports and Exercise*, *50*(11), 2277–2284.

418. Silva-Jose, C., Sánchez-Polán, M., Barakat, R., Gil-Ares, J., & Refoyo, I. (2022). Level of Physical Activity in Pregnant Populations from Different Geographic Regions: A Systematic Review. *Journal of Clinical Medicine*, *11*(15), 4638.

419. Lewis, J. (2008). Ekila: Blood, Bodies, and Egalitarian Societies. *Source: The Journal of the Royal Anthropological Institute*, *14*(2), 297–315.

420. Hinman, S. K., Smith, K. B., Quillen, D. M., & Smith, M. S. (2015). Exercise in Pregnancy. *Sports Health*, *7*(6), 527–531.

421. Emmott, E. (2016). Access to Alloparents. In V. Weekes-Shackelford, T. K. Shackelford, & V. A. Weekes-Shackelford (Eds.), *Encyclopedia of Evolutionary Psychological Science* (pp. 1–4). Springer International Publishing.

422. Emmott, E. H., Myers, S., & Page, A. E. (2021). Who cares for women with children? Crossing the bridge between disciplines. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *376*(1827), 20200019.

423. Westerterp, K. R. (2018). Changes in physical activity over the lifespan: impact on body composition and sarcopenic obesity. *Obesity Reviews*, *19*(S1), 8–13.

424. Füzéki, E., Engeroff, T., & Banzer, W. (2017). Health Benefits of Light-Intensity Physical Activity: A Systematic Review of Accelerometer Data of the National Health and Nutrition Examination Survey (NHANES). *Sports Medicine (Auckland, N.Z.)*, *47*(9), 1769–1793.

425. Button, K. S., Ioannidis, J. P. A., Mokrysz, C., Nosek, B. A., Flint, J., Robinson, E. S. J., & Munafò, M. R. (2013). Power failure: why small sample size undermines the reliability of neuroscience. *Nature Reviews Neuroscience 2013 14:5*, *14*(5), 365–376.

426. van Sluijs, E. M. F., Ekelund, U., Crochemore-Silva, I., Guthold, R., Ha, A., Lubans, D., Oyeyemi, A. L., Ding, D., & Katzmarzyk, P. T. (2021). Physical activity

behaviours in adolescence: current evidence and opportunities for intervention. *The Lancet*, *398*(10298), 429–442.

427. Hochberg, Z., & Konner, M. (2020). Emerging Adulthood, a Pre-adult Life-History Stage. *Frontiers in Endocrinology*, *10*, 918.
428. Kretschmer, L., Salali, G. D., Andersen, L. B., Hallal, P. C., Northstone, K., Sardinha, L. B., Dyble, M., Bann, D., Andersen, L. B., Anderssen, S., Cardon, G., Davey, R., Jago, R., Janz, K. F., Kriemler, S., Møller, N., Northstone, K., Pate, R., Puder, J. J., … International Children’s Accelerometry Database (ICAD) Collaborators. (2023). Gender differences in the distribution of children’s physical activity: evidence from nine countries. *International Journal of Behavioral Nutrition and Physical Activity*, *20*(1), 103.
429. Bhutta, Z. A., Berkley, J. A., Bandsma, R. H. J., Kerac, M., Trehan, I., & Briend, A. (2017). Severe childhood malnutrition. *Nature Reviews Disease Primers*, *3*(1), 1–18.
430. Martorell, R. (1999). The Nature of Child Malnutrition and Its Long-Term Implications. *Food and Nutrition Bulletin*, *20*(3), 288–292.
431. Suzuki, I., Okuda, M., Tanaka, M., Inoue, S., Tanaka, S., & Tanaka, C. (2018). Variability in school children’s activity occurs in the recess and before-school periods. *Pediatrics International*, *60*(8), 727–734.
432. Kilius, E., Samson, D. R., Lew-Levy, S., Sarma, M. S., Patel, U. A., Ouamba, Y. R., Miegakanda, V., Gettler, L. T., & Boyette, A. H. (2021). Gender differences in BaYaka forager sleep-wake patterns in forest and village contexts. *Scientific Reports*, *11*(1), 13658.
433. Hagenauer, M. H., & Lee, T. M. (2013). Adolescent sleep patterns in humans and laboratory animals. *Hormones and Behavior*, *64*(2), 270–279.

434. Brazendale, K., Beets, M. W., Armstrong, B., Weaver, R. G., Hunt, E. T., Pate, R. R., Brusseau, T. A., Bohnert, A. M., Olds, T., Tassitano, R. M., Tenorio, M. C. M., Garcia, J., Andersen, L. B., Davey, R., Hallal, P. C., Jago, R., Kolle, E., Kriemler, S., Kristensen, P. L., … van Sluijs, E. M. F. (2021). Children's moderate-to-vigorous physical activity on weekdays versus weekend days: a multi-country analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *18*(1), 1–13.

435. *Millennium Cohort Study Sixth Sweep (MCS6) Prepared for the Centre for Longitudinal Studies, UCL Institute of Education Ipsos MORI | Millennium Cohort Study Sixth Sweep-Technical Report*. (2017). http://www.ipsos-mori.com/terms.http://www.ipsos-mori.com/terms.

436. John, D., Tang, Q., Albinali, F., & Intille, S. (2019). An Open-Source Monitor-Independent Movement Summary for Accelerometer Data Processing. *Journal for the Measurement of Physical Behaviour*, *2*(4), 268–281.

437. Karas, M., Muschelli, J., Leroux, A., Urbanek, J. K., Wanigatunga, A. A., Bai, J., Crainiceanu, C. M., & Schrack, J. A. (2022). Comparison of Accelerometry-Based Measures of Physical Activity: Retrospective Observational Data Analysis Study. *JMIR mHealth and uHealth*, *10*(7), e38077.

438. White, T., Westgate, K., Wareham, N. J., & Brage, S. (2016). Estimation of Physical Activity Energy Expenditure during Free-Living from Wrist Accelerometry in UK Adults. *PLOS ONE*, *11*(12), e0167472.

439. Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*, 1–48.

440. Rowlands, A., Davies, M., Dempsey, P., Edwardson, C., Razieh, C., & Yates, T. (2020). Wrist-worn accelerometers: recommending ~1.0 m g as the minimum

clinically important difference (MCID) in daily average acceleration for inactive adults. *British Journal of Sports Medicine*, *55*(14), bjsports-2020-102293.

441. Williams, J. A., Zimmerman, F. J., & Bell, J. F. (2013). Norms and Trends of Sleep Time Among US Children and Adolescents. *JAMA Pediatrics*, *167*(1), 55–60.
442. Paruthi, S., Brooks, L. J., D'Ambrosio, C., Hall, W. A., Kotagal, S., Lloyd, R. M., Malow, B. A., Maski, K., Nichols, C., Quan, S. F., Rosen, C. L., Troester, M. M., & Wise, M. S. (2016). Consensus Statement of the American Academy of Sleep Medicine on the Recommended Amount of Sleep for Healthy Children: Methodology and Discussion. *Journal of Clinical Sleep Medicine: JCSM: Official Publication of the American Academy of Sleep Medicine*, *12*(11), 1549–1561.
443. McLellan, G., Arthur, R., Donnelly, S., & Buchan, D. S. (2020). Segmented sedentary time and physical activity patterns throughout the week from wrist-worn ActiGraph GT3X+ accelerometers among children 7–12 years old. *Journal of Sport and Health Science*, *9*(2), 179–188.
444. Arundell, L., Hinkley, T., Veitch, J., & Salmon, J. (2015). Contribution of the After-School Period to Children's Daily Participation in Physical Activity and Sedentary Behaviours. *PLOS ONE*, *10*(10), e0140132.
445. Belcher, B. R., Wolff-Hughes, D. L., Dooley, E. E., Staudenmayer, J., Berrigan, D., Eberhardt, M. S., & Troiano, R. P. (2021). US Population-referenced Percentiles for Wrist-Worn Accelerometer-derived Activity. *Medicine and Science in Sports and Exercise*, *53*(11), 2455–2464.
446. Ricardo, L. I. C., Hallal, P., Domingues, M. R., Oliveira, R. S., Blumenberg, C., Tornquist, D., Tornquist, L., Barros, F., & Crochemore-Silva, I. (2022). Association between objectively measured physical activity of parents and children: The 2015 Pelotas birth cohort. *Scandinavian Journal of Medicine & Science in Sports*, *32*(8), 1287–1296.

447. Vandenbroeck, P., Goossens, J., & Clemens, M. (2007). *Foresight: Tackling Obesities: Future Choices - Building the Obesity System Map*.

448. Bann, D., Courtin, E., Davies, N. M., & Wright, L. (2023). Dialling back ‘impact’ claims: researchers should not be compelled to make policy claims based on single studies. *International Journal of Epidemiology*, dyad181.

449. Grize, L., Bringolf-Isler, B., Martin, E., & Braun-Fahrländer, C. (2010). Trend in active transportation to school among Swiss school children and its associated factors: three cross-sectional surveys 1994, 2000 and 2005. *International Journal of Behavioral Nutrition and Physical Activity*, *7*(1), 28.

450. Herzig, M., Dössegger, A., Mäder, U., Kriemler, S., Wunderlin, T., Grize, L., Brug, J., Manios, Y., Braun-Fahrländer, C., & Bringolf-Isler, B. (2012). Differences in weight status and energy-balance related behaviors among schoolchildren in German-speaking Switzerland compared to seven countries in Europe. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 1–10.

451. Morris, J. N., Heady, J. A., Raffle, P. A., Roberts, C. G., & Parks, J. W. (1953). Coronary heart-disease and physical activity of work. *Lancet (London, England)*, *262*(6796), 1111–1120; concl.

452. Chaudhary, N., & Swanepoel, A. (2023). Editorial Perspective: What can we learn from hunter-gatherers about children’s mental health? An evolutionary perspective. *Journal of Child Psychology and Psychiatry*, *n/a*(n/a).

453. Marlowe, F. (2002). Why the Hadza are still hunter-gatherers. *Ethnicity, Huntergatherers, and the ‘Other’, Ed. S. Kent*, 247–281.

454. DiPietro, L., Al-Ansari, S. S., Biddle, S. J. H., Borodulin, K., Bull, F. C., Buman, M. P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P. C., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., … Willumsen, J. F. (2020). Advancing the global physical

activity agenda: recommendations for future research by the 2020 WHO physical activity and sedentary behavior guidelines development group. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 143.

455. Gurven, M., Stieglitz, J., Trumble, B., Blackwell, A. D., Beheim, B., Davis, H., Hooper, P., & Kaplan, H. (2017). The Tsimane Health and Life History Project: Integrating anthropology and biomedicine. *Evolutionary Anthropology: Issues, News, and Reviews*, *26*(2), 54–73.

456. Ekelund, U., Luan, J., Sherar, L. B., Esliger, D. W., Griew, P., & Cooper, A. (2012). Moderate to Vigorous Physical Activity and Sedentary Time and Cardiometabolic Risk Factors in Children and Adolescents. *JAMA*, *307*(7), 704–712.

457. Goodman, A., Page, A. S., Cooper, A. R., Kordas, K., Davey, R., Pate, R. R., Salmon, J., Andersen, L. B., Froberg, K., Sardinha, L., Anderssen, S., Timperio, A., Janz, K. F., Kreimler, S., Hallal, P., van Sluijs, E., Sutton, G. P., Ekelund, U., & Sherar, L. (2014). Daylight saving time as a potential public health intervention: An observational study of evening daylight and objectively-measured physical activity among 23,000 children from 9 countries. *International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 1–9.

458. Atkin, A. J., Sharp, S. J., Corder, K., & Van Sluijs, E. M. F. (2014). Prevalence and correlates of screen time in youth: an international perspective. *American Journal of Preventive Medicine*, *47*(6), 803–807.

459. Brazendale, K., Beets, M. W., Bornstein, D. B., Moore, J. B., Pate, R. R., Weaver, R. G., Falck, R. S., Chandler, J. L., Andersen, L. B., Anderssen, S. A., Cardon, G., Cooper, A., Davey, R., Froberg, K., Hallal, P. C., Janz, K. F., Kordas, K., Kriemler, S., Puder, J. J., … van Sluijs, E. M. F. (2016). Equating accelerometer estimates among youth: The Rosetta Stone 2. *Journal of Science and Medicine in Sport*, *19*(3), 242–249.

460. Mitchell, J. A., Dowda, M., Pate, R. R., Kordas, K., Froberg, K., Sardinha, L. B., Kolle, E., & Page, A. (2017). Physical Activity and Pediatric Obesity: A Quantile Regression Analysis. *Medicine and Science in Sports and Exercise*, *49*(3), 466–473.

461. Kuzik, N., Carson, V., Andersen, L. B., Sardinha, L. B., Grøntved, A., Hansen, B. H., & Ekelund, U. (2017). Physical Activity and Sedentary Time Associations with Metabolic Health Across Weight Statuses in Children and Adolescents. *Obesity*, *25*(10), 1762–1769.

462. Tarp, J., Bugge, A., Andersen, L. B., Sardinha, L. B., Ekelund, U., Brage, S., & Møller, N. C. (2017). Does adiposity mediate the relationship between physical activity and biological risk factors in youth?: a cross-sectional study from the International Children's Accelerometry Database (ICAD). *International Journal of Obesity (2005)*, *42*(4), 671–678.

463. Renninger, M., Hansen, B. H., Steene-Johannessen, J., Kriemler, S., Froberg, K., Northstone, K., Sardinha, L., Anderssen, S. A., Andersen, L. B., & Ekelund, U. (2020). Associations between accelerometry measured physical activity and sedentary time and the metabolic syndrome: A meta-analysis of more than 6000 children and adolescents. *Pediatric Obesity*, *15*(1), e12578.

464. Wijndaele, K., White, T., Andersen, L. B., Bugge, A., Kolle, E., Northstone, K., Wedderkopp, N., Ried-Larsen, M., Kriemler, S., Page, A. S., Puder, J. J., Reilly, J. J., Sardinha, L. B., Van Sluijs, E. M. F., Sharp, S. J., Brage, S., Ekelund, U., Andersen, L. B., Atkin, A. J., … Van Sluijs, E. M. F. (2019). Substituting prolonged sedentary time and cardiovascular risk in children and youth: A meta-analysis within the International Children's Accelerometry database (ICAD). *International Journal of Behavioral Nutrition and Physical Activity*, *16*(1), 1–10.

465. Bernhardsen, G. P., Stensrud, T., Hansen, B. H., Steene-Johannesen, J., Kolle, E., Nystad, W., Anderssen, S. A., Hallal, P. C., Janz, K. F., Kriemler, S., Andersen, L. B., Northstone, K., Resaland, G. K., Sardinha, L. B., van Sluijs, E. M. F., Ried-Larsen, M., Ekelund, U., Andersen, L. B., Anderssen, S., … van Sluijs, E. M. F. (2020). Birth weight, cardiometabolic risk factors and effect modification of physical activity in children and adolescents: pooled data from 12 international studies. *International Journal of Obesity 2020 44:10*, *44*(10), 2052–2063.

466. Werneck, A. O., Silva, D. R., Oyeyemi, A. L., Fernandes, R. A., Steene-Johannesen, J., Andersen, L. B., Northstone, K., & Sardinha, L. B. (2020). Physical activity attenuates metabolic risk of adolescents with overweight or obesity: the ICAD multi-country study. *International Journal of Obesity 2020 44:4*, *44*(4), 823–829.

467. Werneck, A. O., Jago, R., Kriemler, S., Andersen, L. B., Wedderkopp, N., Northstone, K., Salmon, J., & van Sluijs, E. M. F. (2021). Association of change in the school travel mode with changes in different physical activity intensities and sedentary time: A International Children's Accelerometry Database Study. *Preventive Medicine*, *153*, 106862.

468. Collings, P. J., Grøntved, A., Jago, R., Kriemler, S., Northstone, K., Puder, J. J., Salmon, J., Sardinha, L. B., Steene-Johannessen, J., van Sluijs, E. M. F., Sherar, L. B., Esliger, D. W., & Ekelund, U. (2021). Cross-sectional and prospective associations of sleep duration and bedtimes with adiposity and obesity risk in 15 810 youth from 11 international cohorts. *Pediatric Obesity*, e12873.

469. Ikeda, E., Guagliano, J. M., Atkin, A. J., Sherar, L. B., Ekelund, U., Hansen, B., Northstone, K., van Sluijs, E., Salmon, J., Riddoch, C., Judge, K., Cooper, A., Griew, P., Andersen, L. B., Anderssen, S., Cardon, G., Davey, R., Hallal, P., Jago, R., … On behalf of the International Children's Accelerometry Database (ICAD) Collaborators. (2022). Cross-sectional and longitudinal associations of active

travel, organised sport and physical education with accelerometer-assessed moderate-to-vigorous physical activity in young people: the International Children's Accelerometry Database. *International Journal of Behavioral Nutrition and Physical Activity*, *19*(1), 41.

470. Gammon, C., Atkin, A. J., Corder, K., Ekelund, U., Hansen, B. H., Sherar, L. B., Andersen, L. B., Anderssen, S., Davey, R., Hallal, P. C., Jago, R., Kriemler, S., Kristensen, P. L., Kwon, S., Northstone, K., Pate, R., Salmon, J., Sardinha, L. B., Van Sluijs, E. M. F., & Collaborators, O. B. of the I. C. A. D. (icad). (2022). Influence of Guideline Operationalization on Youth Activity Prevalence in the International Children's Accelerometry Database. *Medicine & Science in Sports & Exercise*, *54*(7), 1114.

471. Mattocks, C., Ness, A., Leary, S., Tilling, K., Blair, S. N., Shield, J., Deere, K., Saunders, J., Kirkby, J., Smith, G. D., Wells, J., Wareham, N., Reilly, J., & Riddoch, C. (2008). Use of accelerometers in a large field-based study of children: protocols, design issues, and effects on precision. *Journal of Physical Activity & Health*, *5 Suppl 1*(SUPPL. 1).

472. Crawford, D., Cleland, V., Timperio, A., Salmon, J., Andrianopoulos, N., Roberts, R., Giles-Corti, B., Baur, L., & Ball, K. (2010). The longitudinal influence of home and neighbourhood environments on children's body mass index and physical activity over 5 years: the CLAN study. *International Journal of Obesity 2010 34:7*, *34*(7), 1177–1187.

473. Riddoch, C., Edwards, D., Page, A., Froberg, K., Anderssen, S. A., Wedderkopp, N., Brage, S., Cooper, A. R., Sardinha, L. B., Harro, M., Klasson-Heggebø, L., van Mechelen, W., Boreham, C., Ekelund, U., & Andersen, L. B. (2005). The European Youth Heart Study—Cardiovascular Disease Risk Factors in Children:

Rationale, Aims, Study Design, and Validation of Methods. *Journal of Physical Activity and Health*, *2*(1), 115–129.

474. Jackson, M., Crawford, D., Campbell, K., & Salmon, J. (2008). Are parental concerns about children's inactivity warranted, and are they associated with a supportive home environment? *Research Quarterly for Exercise and Sport*, *79*(3), 274–282.
475. Salmon, J., Campbell, K. J., & Crawford, D. A. (2006). Television viewing habits associated with obesity risk factors: a survey of Melbourne schoolchildren. *Medical Journal of Australia*, *184*(2), 64–67.
476. Zahner, L., Puder, J. J., Roth, R., Schmid, M., Guldimann, R., Pühse, U., Knöpfli, M., Braun-Fahrländer, C., Marti, B., & Kriemler, S. (2006). A school-based physical activity program to improve health and fitness in children aged 6-13 years ('Kinder-Sportstudie KISS'): Study design of a randomized controlled trial [ISRCTN15360785]. *BMC Public Health*, *6*(1), 1–12.
477. Wolff-Hughes, D. L., Bassett, D. R., & Fitzhugh, E. C. (2014). Population-Referenced Percentiles for Waist-Worn Accelerometer-Derived Total Activity Counts in U.S. Youth: 2003 – 2006 NHANES. *PLoS ONE*, *9*(12), e115915.
478. Victora, C. G., Hallal, P. C., Araújo, C. L. P., Menezes, A. M. B., Wells, J. C. K., & Barros, F. C. (2008). Cohort Profile: The 1993 Pelotas (Brazil) Birth Cohort Study. *International Journal of Epidemiology*, *37*(4), 704–709.
479. Panter-Brick, C. (1996). Seasonal and sex variation in physical activity levels among agro-pastoralists in Nepal. *American Journal of Physical Anthropology*, *100*(1), 7–21.
480. Esparza, J., Fox, C., Harper, I. T., Bennett, P. H., Schulz, L. O., Valencia, M. E., & Ravussin, E. (2000). Daily energy expenditure in Mexican and USA Pima Indians:

Low physical activity as a possible cause of obesity. *International Journal of Obesity*, *24*(1), 55–59.

481. Sayre, M. K., Pike, I. L., & Raichlen, D. A. (2019). High levels of objectively measured physical activity across adolescence and adulthood among the Pokot pastoralists of Kenya. *American Journal of Human Biology*, *31*(1).

482. Ocobock, C., Soppela, P., Turunen, M., Stenbäck, V., Herzig, K.-H., Rimbach, R., & Pontzer, H. (2022). Reindeer herders from subarctic Finland exhibit high total energy expenditure and low energy intake during the autumn herd roundup. *American Journal of Human Biology*, *34*(4), e23676.

Appendices

List of Supplemental Tables

List of supplemental figures

Appendix A Appendix to Chapter 3: Gender Differences in the distribution of physical activity in the International Children’s Accelerometry Database

Table S A-1: Summary of literature published using the ICAD dataset, as available at https://www.mrc-epid.cam.ac.uk/research/studies/icad/ . Table is orded by year of publication. Reviewed literature was last updated on 27/7/23.

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
Sherar et al.,	International children's accelerometry database (ICAD): Design and methods[259]	2011	All	NA	NA	NA	Summary of the methodology in setting up ICAD
Ekelund et al.,	Moderate to Vigorous Physical Activity and Sedentary Time and Cardiometabolic Risk Factors in Children and Adolescents[456]	2012	Ballabeina, EYHS, KISS, ALSPAC, Pelotas, NHANES, CSCIS, PEACH, Speedy	Cardiometabolic risk factors (Waist circumference, systolic blood pressure, fasting triglycerides, high-density lipoprotein cholesterol, and insulin)	MVPA and Sedentary Time	Time in MVPA was significantly associated with all cardiometabolic outcomes independent of gender, age, monitor wear time, time spent sedentary, and waist circumference. Sedentary was not associated with any outcome	Large increases in MVPA (10min/day) were associated with small changes in CM outcome (0.5cm waist). Seems to be variation in the amount of variation between studies.

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
						independent of MVPA (But isotemporal substitution)	
Kwon et al.,	Tracking of accelerometry-measured physical activity during childhood: ICAD pooled analysis[296]	2012	ALSPAC, CLAN, Iowa Bone Development Study, HEAPS, PEACH	MVPA, MPA and VPA at follow-up	MVPA, MPA and VPA at baseline	VPA tracking for boys with high baseline VPA was higher than boys with low baseline VPA. VPA and MVPA was less stable for girls with higher values at baseline.	Girls engaged in approximately 20 minutes/day less MVPA than boys. Mean activity fell in all activity categories between baseline and follow-up.
Goodman et al.,	Daylight saving time as a potential public health intervention: an observational study of evening daylight and objectively-measured	2014	(Subset to 439 individuals who recorded over their countries day light savings date)	Change in PA (Counts per minute) with more/less evening sunlight	Evening day light length	Longer evening daylight was independently associated with a small increase in daily physical activity (0.03-0.07 SD's). Most change in PA is seen in the evening (Time when	Effect size varied by study sample. Most consistent effect in mainland Europe studies, no effect in Brazil/Portugal studies

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
	physical activity among 23,000 children from 9 countries[457]					daylight savings benefit in summer)	
Atkin et al.,	Prevalence and Correlates of Screen Time in Youth: An International Perspective[458]	2014	CLAN, Pelotas, EYHS, PEACH, IBDS, NHANES	Screen Time	gender, age, weight status, maternal education, and ethnicity	Two thirds of participants exceeded 2 hours/day of screen time. Screen time higher in overweight	Screen time ≠ sedentary time, screen time based on self-reports, when objective sedentary is available in this study
Hildebrand et al.,	Association between birth weight and objectively measured sedentary time is mediated by central adiposity: data in 10,793 youth from the International	2015	ALSPAC, EYHS, KISS, Pelotas, SPEEDY	Sedentary Behaviour	Birth Weight, Central Adiposity	Birthweight was positively associated with sedentary time and waist circumference. Waist circumference mediated the effect of birthweight on sedentary time.	Possible variation in variation of cpm, and sedentary time. 1kg in birthweight was associated with 4mins of sedentary behaviour

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
	Children's Accelerometry Database[325]						
Sherar et al	Association between maternal education and objectively measured physical activity and sedentary time in adolescents[299]	2015	EYHS, KISS, ALSPAC, Peach, Clan, Heaps, Pelotas	cpm, Sedentary, Moderate-Vigorous, and proportion meeting 60min/day	Mothers Education,	Children of most educated mothers spent 10min/day more in sedentary, and ~10min/day less in light activity	Difference between children of highest educated (Uni) and least educated (High School) - but neither group different from the middle grouping (College). Difference not seen in cpm or MVPA
Cooper et al.,	Objectively measured physical activity and sedentary time in youth: the International children's accelerometry	2015	All	cpm, Sedentary, Moderate-Vigorous, and proportion meeting 60min/day	age, gender, weight status, country	Boys were less sedentary and more active than girls. PA decreased from age 5 (-4.2%/year). Disparity between nations increased with age.	Associations remained consistent across nations (despite differing PA in those countries). cpm seemed to vary variously across ages (but issue with

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
	database (ICAD)[7]						different studies contributing at each age). BMI not a factor in PA, until age 6 then because associated.
Corder et al.,	Age-related patterns of vigorous-intensity physical activity in youth: The International Children's Accelerometry Database[293]	2016	All	VPA	Age, gender, ethnicity, country	Annual reduction in VPA was greater than the reduction in MVPA (6.9% vs 6.0%), larger decrease for girl's vs boys, non-white vs white,	% change varied between regions. Cross sectional exploration of age effects. Despite difference in MPA vs VPA - drop is bigger in MPA when measured as time.
Brazendale et al.,	Equating accelerometer estimates among youth: The Rosetta Stone 2[459]	2016	All	Agreement between cut points	MVPA measured with differing cut points	MVPA varied from 30mins to 130min depending on cut point used.	-

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
Atkin et al.,	Harmonising data on the correlates of physical activity and sedentary behaviour in young people: Methods and lessons learnt from the international Children's Accelerometry database (ICAD)[312]	2017	All	NA	NA	NA	Summary of the methodology in setting up ICAD (2)
Mitchell et al.,	Physical Activity and Paediatric Obesity[460]	2017	ALSPAC, EYHS, NHANES, PEACH	MVPA	BMI and Waist Circumference	MVPA was negatively associated with BMI and waist circumference, Sed was positively. MVPA attenuated the effect of sed.	

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
Kuzik, et al.,	Physical Activity and Sedentary Time Associations with Metabolic Health Across Weight Statuses in Children and Adolescents[461]	2017		Metabolic Health by Weight Status (Categorical)	Activity (Threshold)	Higher sedentary or lower MVPA associated with metabolic markers of unhealth in all weight groups	Could have used weight as a categorical. Metabolic health composite of measures previously used in ICAD studies (Ekelund 2012)
Harrison et al.,	Weather and children's physical activity; how and why do relationships vary between countries?[328]	2017		cpm	Weather at time of recording	cpm were lower when days were longer, less windy, less rain. Temperature had a linear effect between 0-20, then plateau	More active nations showed less fluctuation with weather. Day length could be explained by high PA in active Scandinavians in summer
Hansen et al.,	Cross-Sectional Associations of Reallocating Time Between Sedentary and Active Behaviours on Cardiometabolic Risk Factors in Young People:	2018	ALSPAC, CoSCIS, EYHS, KISS, NHANES, SPEEDY, PEACH, MAGIC, Ballabeina	Cardiometabolic risk factors	Physical Activity (All)	Replacing 10 min of sedentary time with 10 min of MVPA showed favourable associations with WC, SBP, LDL-C, insulin, triglycerides, and glucose; the greatest magnitude was observed for	Use a time/exchange isotemporal model of intensities - but not 0 sum as incomplete days included. Generally healthy population examined

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
	An International Children's Accelerometry Database (ICAD) Analysis[326]					insulin (reduction of 2–4%), WC (reduction of 0.5–1%), and triglycerides (1–2%). In addition, replacing 10 min of sedentary time with an equal amount of LPA showed beneficial associations with WC, although only in adolescents.	
Tarp et al.,	Does adiposity mediate the relationship between physical activity and biological risk factors in youth?: a cross-sectional study from the International Children's Accelerometry	2018	CoSCIS, EYHS, NHANES	Composite risk score from blood pressure, insulin, glucose, triacylglycerol and HDL-cholesterol.	MVPA	Meeting guidelines gave a composite score 0.31SD lower. .07 of this is attributable to the mediating role of adiposity	Some of the effect was explained by WC ration, but 22% was still attributable to a direct effect. When cut offs were lower, the direct effect changed but the indirect through adiposity did not. Effect in boys was a little stronger (-0.22 vs -0.18 direct

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
	Database (ICAD)[462]						effect). NHANES had low % of girls meeting targets so potentially skewing results
Tarp et al.,	Physical activity intensity, bout-duration, and cardiometabolic risk markers in children and adolescents[297]	2018	All (Minus pre-schoolers)	cardiometabolic risk markers	Physical Activity (Total/Bouted)	Higher PA was associated with lower risk score, but bout length was not associated. Total over bouted is better measure for cardiometabolic risk score.	Given the observation of bouts not being as useful - why not use mean cpm? Use a time/exchange isotemporal model of intensities - but not 0 sum as incomplete days included.
Kwon et al.,	A closer look at the relationship among accelerometer-based physical activity metrics: ICAD pooled data[301]	2019	All (Minus CHAMPS US, MAGIC)	Correlation between activity measures	Activity Measures	Total counts were highly correlated with wear time. MVPA did not correlate with wear time. SB and LPA were correlated. MPA and VPA were	Highlights potential collinearity in PA measures. Total counts also skewed by recording length, should standardise to average per minute/hour.

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
						moderately correlated.	
Renninger et al.,	Associations between accelerometry measured physical activity and sedentary time and the metabolic syndrome: A meta-analysis of more than 6000 children and adolescents[463]	2019	ALSPAC, CoSCIS, EYHS, KISS, NHANES	Metabolic Syndrome Prevalence	Physical Activity (Whole Spectrum)	10min of additional MVPA was associated with a 0.88 OR of metabolic syndrome. 10min of VIG had an OR of 0.8. +1hr of SED had an OR of 1.28.	MVPA remained associated after adjustment for SED, SED was attenuated with inclusion of MVPA. No mention of light activity. Low level of MetS in study. Amount of MetS varied between study (entirely absent in KISS)

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
Dias et al.,	International Comparison of the Levels and Potential Correlates of Objectively Measured Sedentary Time and Physical Activity among Three-to-Four-Year-Old Children[294]	2019	(Pre-schoolers) Ballabeina, Belgium Preschool, CHAMPS, IWDS, Glasgow Intervention	Physical Activity	age, gender, country, season, ethnicity, parental education, day of the week (weekday vs weekend), time of sunrise, time of sunset, and hours of daylight	MVPA higher if older, Male, in UK or US, recording in Summer, White, parent educated as far as compulsory age, longer day length	Patterns are similar with cpm, and inverse for sed. However, no effect of ethnicity.
Wijndaele et al.,	Substituting prolonged sedentary time and cardiovascular risk in children and youth: a meta-analysis within the International Children's Accelerometry database (ICAD)[464]	2019	Studies with Cardiovascular markers	Cardiovascular Risk	Persistent Sedentary Behaviour (PSB)	Exchanging 1hour of PSB for non-PSB associated with a decline in BMI. Effect of exchanging 1hr PST for MVPA was 7x greater. Only exchange with MVPA was associated with lower waist circumference and CVRisk	While moving from PST to non-PST or LPA, moving to MVPA had the greatest effect. Does imply that any move away from PST is beneficial, but MVPA is most beneficial. 1hr increase in MVPA is a large increase.

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
Bernhardsen et al.,	Birth weight, cardiometabolic risk factors and effect modification of physical activity in children and adolescents: pooled data from 12 international studies[465]	2020	EYHS, ALPSAC, IBDS, Pelotas, SPEEDY, KISS, MoBa, ASK, PANCS	cardiometabolic risk factors	Birth weight and mediation from physical activity (MVPA)	Most associations between BW and CMD were not attenuated by MVPA - excluding waist circumference in childhood, HDL in adolescence	MVPA was independently associated with CMD. Is BW and PA colinear? Not all included studies had all CMDs - only waist circumference included all studies.
Werneck et al.,	Physical activity attenuates metabolic risk of adolescents with overweight or obesity: the ICAD multi-country study[466]	2020	ALSPAC, EYHS, NHANES	Metabolic Risk Score	Weight status, physical activity (MVPA)	Weight status positively associated with Metabolic Risk Score. In overweight group, being in highest tertile of MVPA attenuated the risk	Attenuation is largely explained by VPA, but not exclusively so. Clearer linearity between tertiles in boys. Highest tertile includes activity above guidelines of 60min/day of MVPA

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
Aadland et al.,	The multivariate physical activity signature associated with metabolic health in children and youth: An International Children's Accelerometry Database (ICAD) analysis[105]	2020	EYHS, ALSPAC, CoSCIS, KISS, PANCs, NHANES, Pelotas	Composite metabolic health score (abdominal fatness, insulin sensitivity, lipid metabolism, blood pressure)	Physical Activity (Whole Spectrum)	Associations were weak for sedentary time and light physical activity, but stronger for time spent in moderate and vigorous intensities	Why not use mean cpm to avoid focussing on individual thresholds.
Van Ekris et al.,	Tracking of total sedentary time and sedentary patterns in youth: a pooled analysis using the International Children's Accelerometry Database (ICAD)[295]	2020	(Longitudinal studies) Speedy, PEACH, ALSPAC, CLAN, EYHS, KISS, HEAPS, IBDS,	Sedentary Behaviour at follow-up	Sedentary Behaviour at Baseline	Sedentary behaviour increased annually by 21.4 min/day. Sedentary behaviour tracked moderately well (those that were most inactive remained so)	Tracking was marginally stronger for boys

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
Steene-Johannessen et al.,	Variations in accelerometry measured physical activity and sedentary time across Europe – harmonized analyses of 47,497 children and adolescents[8]	2020	ALSPAC, Ballabeina, Belgium Pre-school, CHASE, COSCIS, EYHS, GINI, Helena, IDEFICS, ISCOLE, KISS, LISA, MAGIC, MAL-TA, Odense, OPUS, PANCS, PEACH, Space, SPEEDY, Gateshead, BEPA	Physical Activity	Country (Europe), Age, Gender	Variation between nations with lower physical activity levels and prevalence estimates in Southern European countries. Boys were more active and less sedentary in all age-categories. Physically activity stopped increasing from age 5	Difference between genders in cpm seems be stable despite fluctuations. MVPA is similar but not quite as strong. Disparity between nations seems stronger during childhood than adolescence.

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
Werneck et al.,	Association of change in the school travel mode with changes in different physical activity intensities and sedentary time: A International Children's Accelerometry Database Study[467]	2021	(Longitudinal studies) Speedy, PEACH, ALSPAC, CLAN, EYHS, KISS	Moderate, Vigorous and sedentary behaviour	Active School transport	Compared to individuals who maintained active transport, those that moved from passive to active saw an increase in their VPA, moves from active to passive, or remaining passive saw a decrease in MVPA.	3x as many people maintained their mode of transport compared to changed. All increased their sedentary time by follow-up. Remaining active were most active at both waves. SED was least active at both waves. Moving to sedentary had the biggest decline. Only moving to active saw an increase.
Brazendale et al.,	Children's moderate-to-vigorous physical activity on weekdays versus weekend days: a multi-country analysis[434]	2021		MVPA	Day Type	More MVPA on weekdays (Boys +13mins, Girls +9mins). Mainland Europe saw largest effect. Effect was marginally larger for normal/underweight	Study is a test of Structured Days Hypothesis (SDH) (Days with structure are beneficial for health behaviours in youth)

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
						individuals (+~1min)	
Collings et al.,	Cross-sectional and prospective associations of sleep duration and bedtimes with adiposity and obesity risk in 15 810 youth from 11 international cohorts[468]	2021	EYHS, KISS, ALSPAC, Peach, Clan, Heaps	BMI/Adiposity	Sleep (Duration and timing)	Longer sleep was associated with lower adiposity. Early bedtime was associated with lower BMI. Longer sleep at baseline was associated with a favourable change in BMI	The threshold at difference was individuals sleeping >10hrs/day. Effect on adiposity was variable at adolescence (Effect in boys but not girls)
Ikeda et al.,	Assessing the contribution of active travel, organised physical activity and physical education to moderate-to-vigorous	2022	ALSPAC, SPEEDY, CLAN	MVPA and VPA	Active Travel, Organised Sport, PE	Organised Sport and Active Travel were associated with increased volumes of MVPA.	Self and parent report may alter estimates of active travel. Small collection of studies with only UK and AUS. ~4000 missing

Author(s)	Title	Publication Year	Study Inclusion	Outcome Measure	Variable of Interest	Outcomes/Results	Notes/Limitations
	physical activity in children and adolescents: A cross-sectional and prospective analysis[469]						(from an original sample of 8,000)
Gammon et al.,	Interpretation of the youth physical activity guidelines: implications for compliance estimates and associations with health indicators[470]	2022	ALSPAC, CHAMPS, CLAN, EYHS, HEAPS, IOWA Bone Study, KISS, NHANES, Pelotas,	Compliance with assorted health recommendations (>60mins, >15mins VPA)	MVPA, VPA,	Between 5 and 30% of children met different activity thresholds. Of individuals who met MVPA based guidelines, 80% met the VPA guidelines.	No consideration of Sed/Light

A.1 Included Studies in Chapters 3 and 4

A.1.1 Avon Longitudinal Study of Parents and Children (ALSPAC) – UK

The Avon Longitudinal Study of Parents and Children is a longitudinal study conducted in the Bristol area. The study initially recruited 14,541 pregnant women who had expected deliveries between April 1991 and December 2002.[314] This resulted in 14,062 live births, with a further 913 participants joining later (these were from mothers who were eligible at the initial recruitment phase but did not join the study until a later point). In interviews between 2003 and 2007 (approximate ages of 14 to 16years) individuals were invited to wear a waist-worn accelerometer for 7 consecutive days.[471] Of the initial study sample, 6060 individuals contributed valid activity data that was included in ICAD.[259]

A.1.2 Children Living in Active Neighbourhoods Project (CLAN) – Australia

The Children Living in Active Neighbourhoods Project is longitudinal study of 2,096 children from 19 schools in Melbourne, with three waves of data collection.[472] Individuals were initially recruited at ages 10-12 years, and followed up with two additional waves, three and five years later. At each wave physical activity data was recorded using a waist worn accelerometer. Of these 1,126 children provided valid physical activity data that could be incorporated into ICAD.[259]

A.1.3 European Youth Heart Study (EYHS) - Denmark, Estonia, Norway, Portugal

The European Youth Heart Study was conducted in Odense (Denmark), Tartu (Estonia), Oslo (Norway) and Madeira (Portugal), with one sweep in Estonia and Norway, and two sweeps in Denmark and Portugal.[473] Aiming to explore risk factors for cardio-vascular disease, accelerometry data was collected from participating individuals by waist worn accelerometers. At initial recruitment individuals were approximately aged 9 or 15years. From this a total of 1,308 individuals from Denmark, 662 individuals from Estonia, 391 individuals from Norway, and 1242 individuals from Portugal had data that could be incorporated into ICAD.[259]

A.1.4 Healthy Eating and Play Study (HEAPS) – Australia

The Healthy Eating and Play Study is a longitudinal study of children from Melbourne, aged either 5-to-6 years or 10-to-12 years of age at induction to the study, and followed up 4 years later.[474,475] Individuals were requested to provide waist worn accelerometry, with 1,362 having complete data that could be contributed to ICAD.[259]

A.1.5 Kinder-Sportstudie (KISS) – Switzerland

The Kinder-Sportstudie is an intervention study designed to explore whether a school-based physical intervention could increase activity levels in a group of 6-to-13 year olds, conducted in the Aargau and Basel cantons of Switzerland.[476] Within these regions non-random sampling was employed, so as to be representative of the wider demographics of Switzerland. Participating individuals provided accelerometry data before and after the intervention by wearing waist-worn devices. A total of 433 individuals had complete data at baseline which could be contributed to ICAD.[259] While both pre and post intervention data is available, only the pre-test data is included in the present analyses.

A.1.6 National Health and Nutrition Examination Survey (NHANES) – United States of America

The National Health and Nutrition Examination Survey is a repeated cross-sectional study undertaken across the USA and aims to be broadly representative of the national population, with some oversampling of minority groups to ensure statistical power.[260] In the 2003 and the 2005 surveys, waist worn accelerometer data was collected from all consenting individuals aged 6 years or older.[477] Due to privacy concerns, the raw accelerometry files were not made available for inclusion in ICAD.[259] This means that the exact start date of the recording is not available. In the harmonisation process, the start date for each file was set to be between the 1st and 7th of January on the year of recording, with the date picked to match the day of the week on which recording started. Across the two survey years, a total of 5,174 individuals aged between 6 and 18 years had valid accelerometry data that could be included in ICAD.[259]

A.1.7 Pelotas Study – Brazil

The Pelotas Study is a multi-cohort longitudinal study that samples birth cohorts from the city of Pelotas in Brazil, repeated roughly every 10 years.[478] The 1993 cohort consists of all the children born in the City of Pelotas during the calendar year (for whom their parents agreed to participation).[478] Objective physical activity data was collected from a subset of the sample in 2006 using waist worn devices. The subset was consistent of individuals who had been interviewed at every sweep to that point. From the subset collected in 2006, a total of 457 individuals had data that could be contributed to ICAD.[259]

A.2 Exclusion Criteria

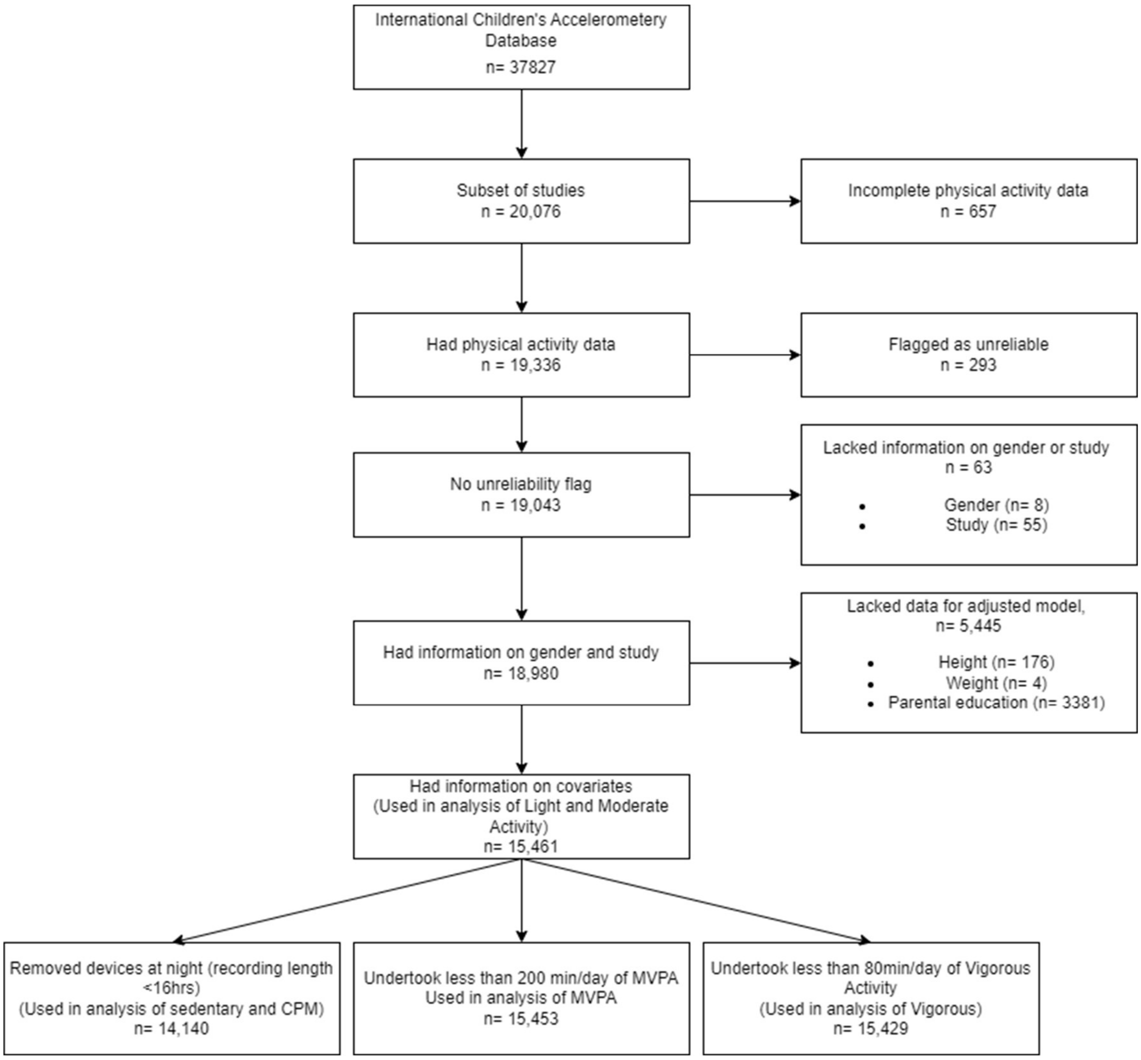


Figure S A-1: Flow of missingness by core variables. Other restrictions were placed on day length and are detailed in the body text.

Table S A-2: Number of individuals with missing data by demographic variable and Gender

	Overall	Girls	Boys
n	885	380	411
Age (mean (SD))	12.77 (3.30)	12.70 (3.33)	12.83 (3.29)
Height (mean (SD))	154.03 (18.25)	150.96 (16.36)	156.78 (19.48)
Weight (mean (SD))	50.83 (19.93)	49.38 (19.58)	52.17 (20.29)
Ethnicity (white) (%)	287 (57.7)	130 (56.0)	157 (59.2)
Country (%)			
Australia	93 (11.6)	53 (13.9)	40 (9.7)
Brazil	1 (0.1)	1 (0.3)	0 (0.0)
Denmark	85 (10.6)	43 (11.3)	42 (10.2)
Estonia	2 (0.2)	1 (0.3)	1 (0.2)
Norway	11 (1.4)	2 (0.5)	3 (0.7)
Portugal	32 (4.0)	15 (3.9)	17 (4.1)
Switzerland	32 (4.0)	17 (4.5)	15 (3.6)
UK	236 (29.4)	99 (26.1)	132 (32.1)
USA	310 (38.7)	149 (39.2)	161 (39.2)
Mothers Education (Beyond Compulsory) (%)	280 (52.4)	146 (54.1)	131 (50.2)
Fathers Education (Beyond Compulsory) (%)	231 (57.3)	125 (62.8)	103 (51.2)
	Reason for Exclusion (%)		
Missing Physical Activity Data	657 (74.2)	300 (78.9)	333 (81.0)
Missing Country	55 (6.2)	0 (0.0)	0 (0.0)
Missing Gender	8 (0.9)	0 (0.0)	0 (0.0)
Flagged as unreliable	165 (18.6)	80 (21.1)	78 (19.0)

A.3 Additional Figures

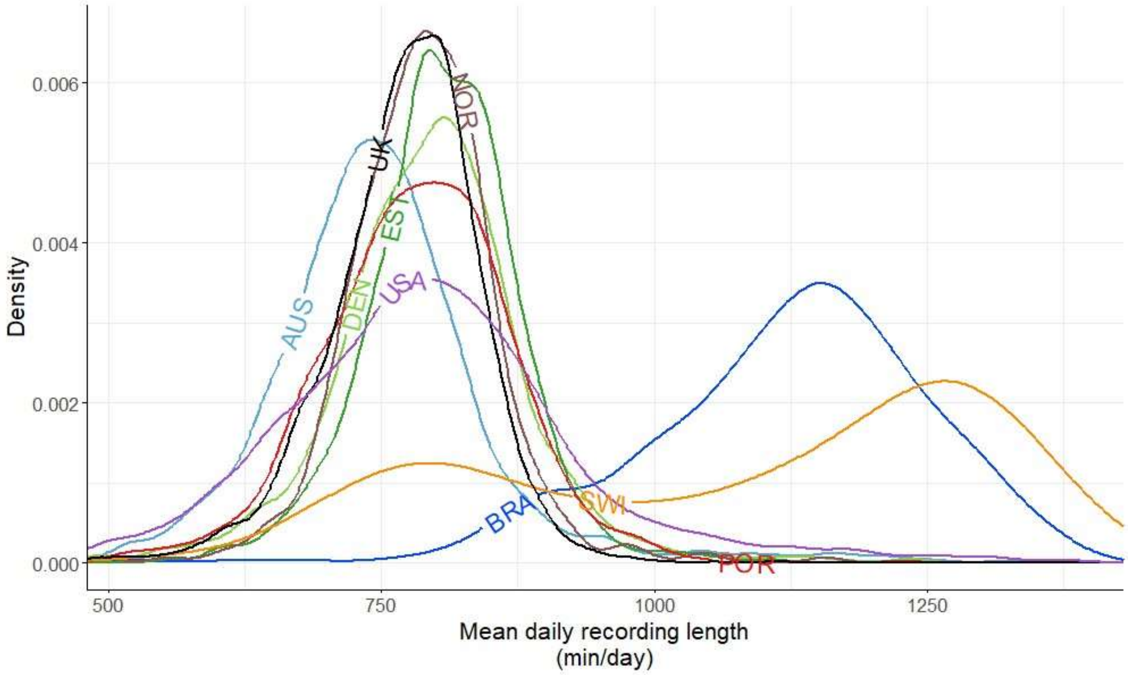


Figure S A-2: Density plot of mean recording length across nations of study.

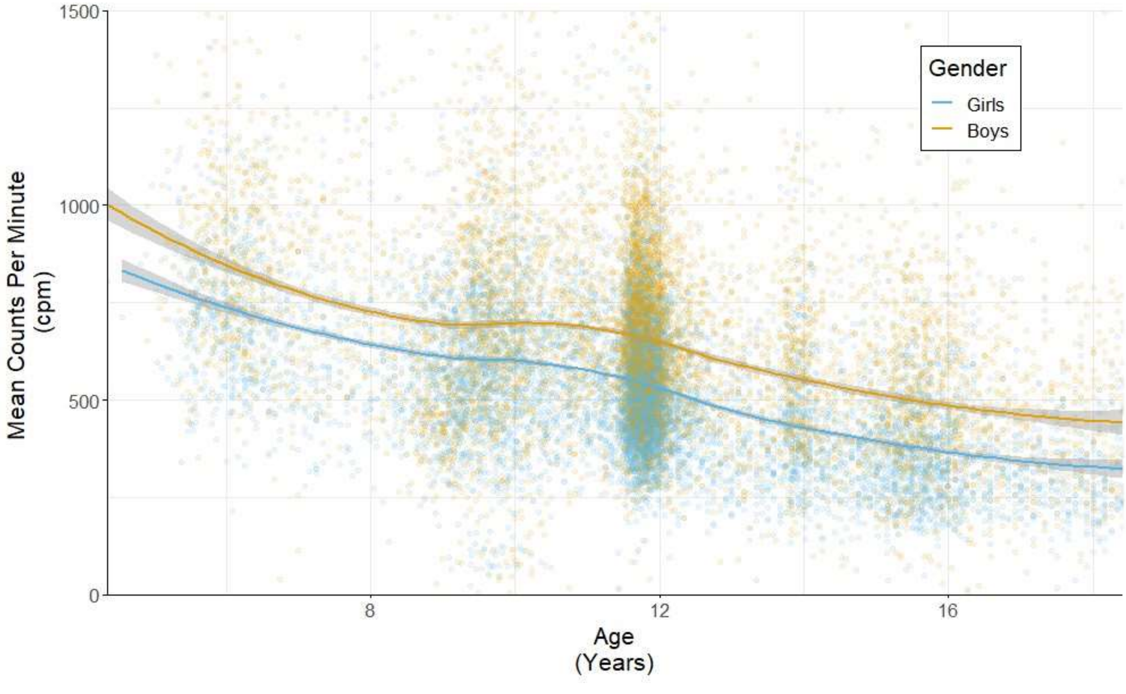


Figure S A-3: Mean counts per minute plotted against age including all individuals in the study. Line is best fit with 95% confidence interval marked in grey. Each colour represents one gender.

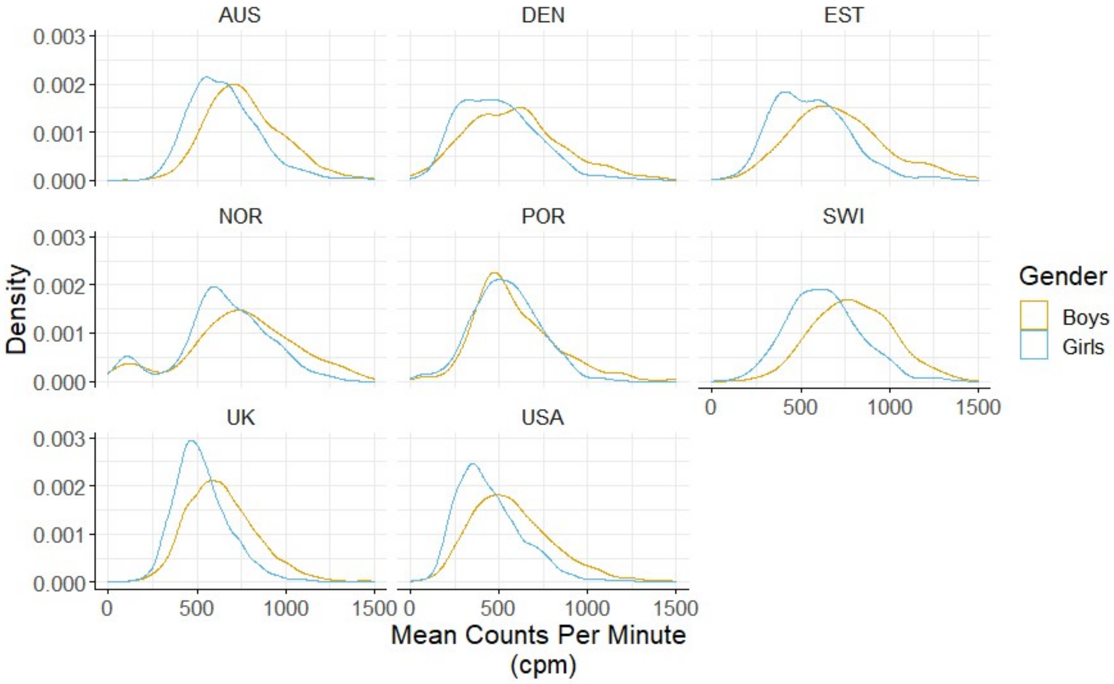


Figure S A-4: Density plot of mean counts per minute (cpm) by gender, presented by nation of study.

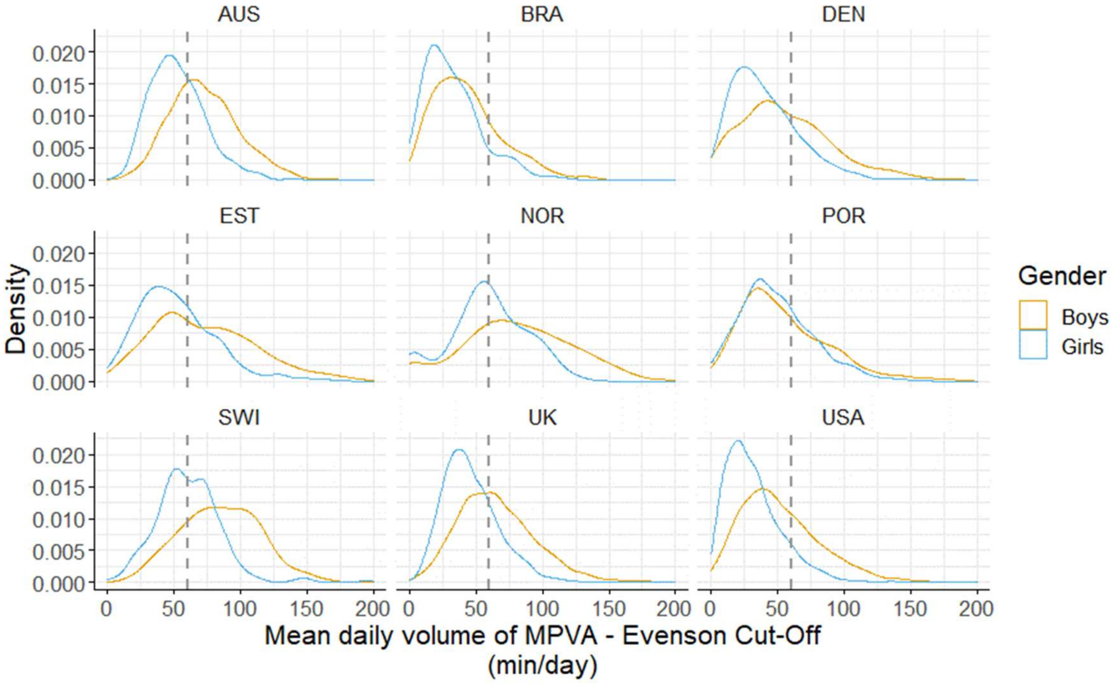


Figure S A-5: Density plot of mean daily minutes of moderate-to-vigorous physical activity (MVPA) by gender, presented by nation of study. Vertical

dashed line represents 60 min/day of MVPA, WHO guidelines for recommend activity levels for a child aged 5-18.

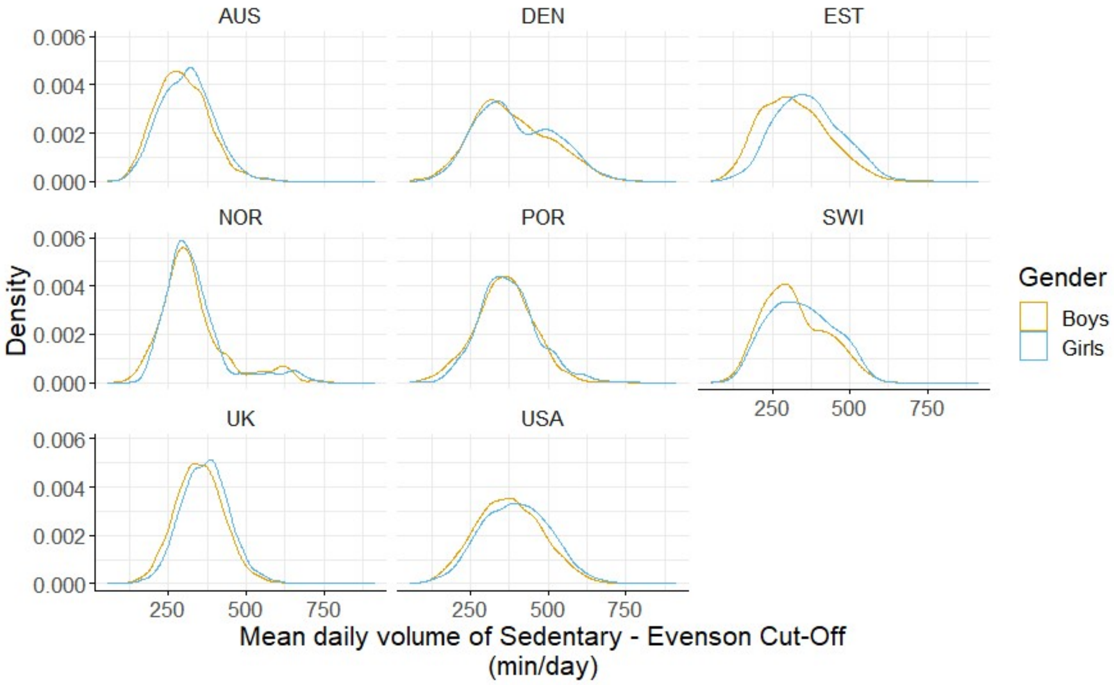


Figure S A-6: Density plot of mean daily minutes of sedentary activity by gender, presented by nation of study.

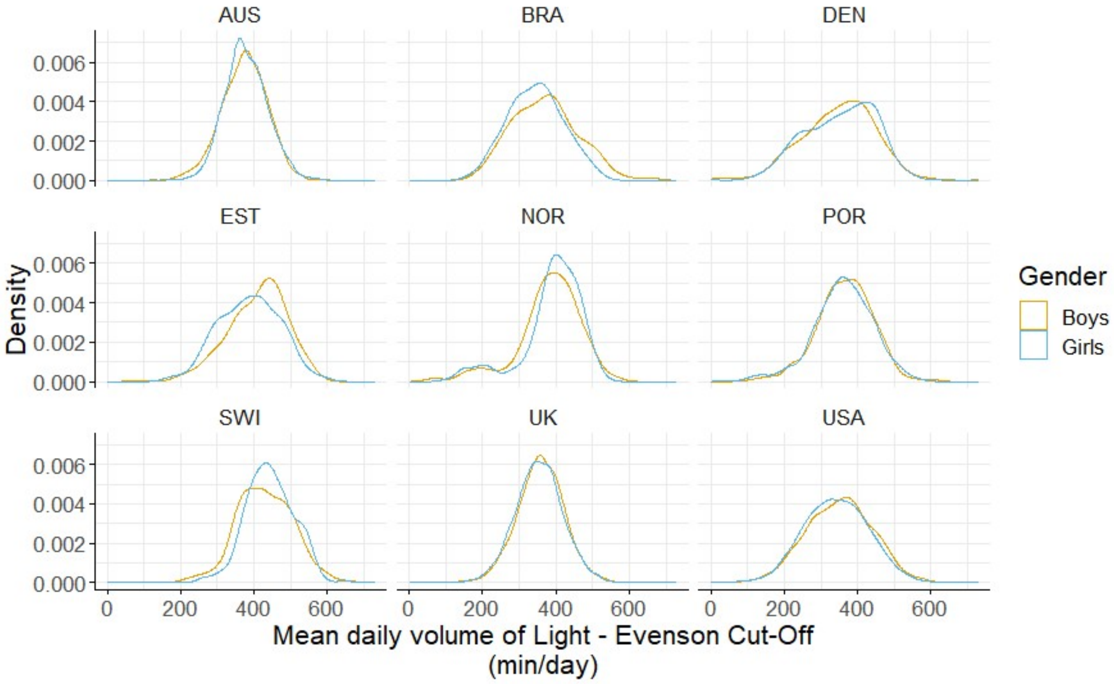


Figure S A-7: Density plot of mean daily minutes of light activity by gender, presented by nation of study.

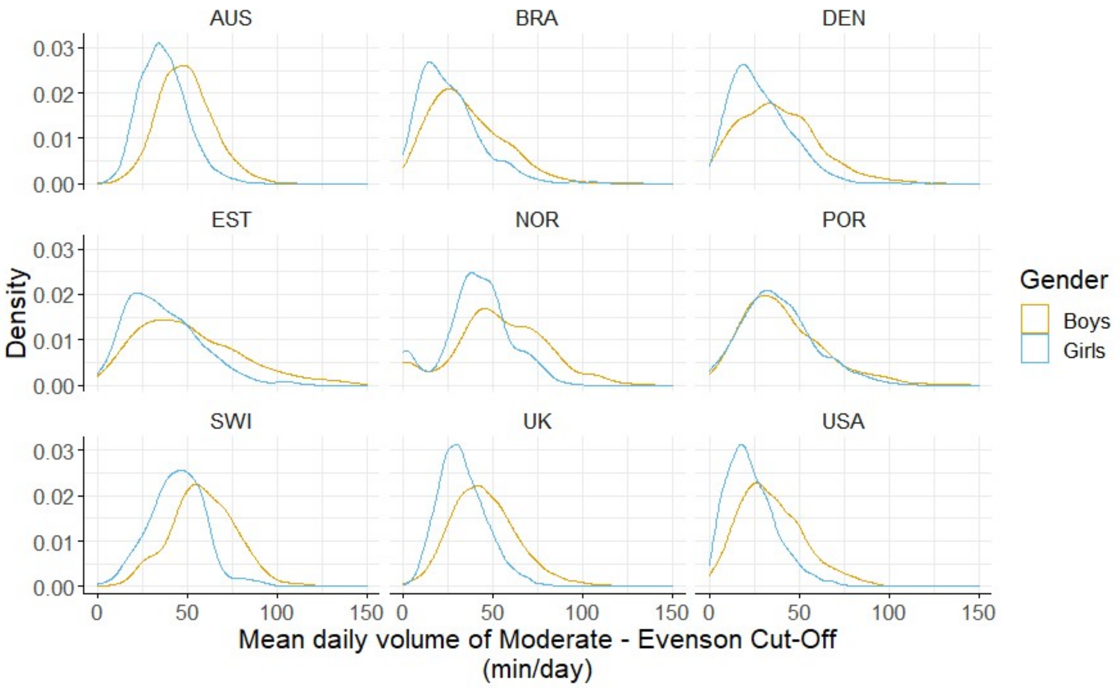


Figure S A-8: Density plot of mean daily minutes of moderate activity by gender, presented by nation of study.

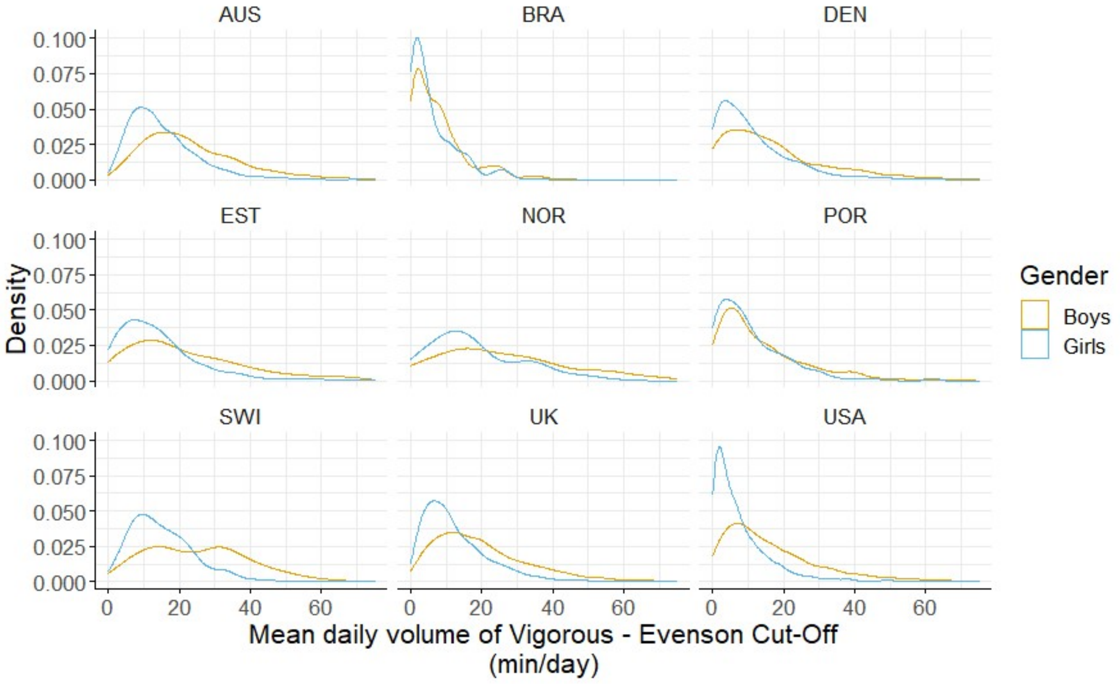


Figure S A-9: Density plot of mean daily minutes of vigorous activity by gender, presented by nation of study.

A.4 Sensitivity Analyses

A.4.1 Unadjusted Models in unrestricted samples

Table S A-3: Association between gender and Counts Per Minute as defined by Evenson cut points for both restricted (as presented in the chapter) and unrestricted sample sizes. Differences in mean, variability and skewness estimated by GAMLSS, a = samples after restriction for complete cases of for parental education, BMI, and country. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error

. * = p<0.05, ** = p<0.01, *** = p<0.001.

		NO distribution		**BCCG distribution**	
Gender	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
Girls (ref) **(Unrestricted Sample)**	9117 (52.3)	530.4	198.0	511.4	0.48
Girls^{a} **(Restricted Sample)**	7377 (52.2)	532.91	200.32	513.31	0.48
Boys **(Unrestricted Sample)**	8387 (47.9)	19.0 (0.56) ***	16.9 (1.07) ***	20.1 (0.61) ***	0.15 (0.02) ***
Boys^{a} **(Restricted Sample)**	6763 (47.8)	19.85 (0.62) ***	16.42 (1.26) ***	21.29 (0.67) ***	0.19 (0.03) ***

*Table S A-4: Association between gender and volumes of moderate-to-vigorous physical activity as defined by Evenson cut points for both restricted (as presented in the chapter) and unrestricted sample sizes. Differences in mean, variability and skewness estimated by GAMLSS, a = samples after restriction for complete cases of for parental education, BMI, and country. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.*

Gender	**N (%)**	**NO distribution**		**BCCG distribution**	
		Mean % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
Girls (ref) **(Unrestricted Sample)**	9802 (51.7)	43.5	24.0	40.3	0.56
Girls^{a} **(Restricted Sample)**	7996 (51.7)	42.94	23.73	39.81	0.57
Boys **(Unrestricted Sample)**	9164 (48.3)	35.1 (0.77) ***	27.8 (1.03) ***	37.0 (0.88) ***	0.07 (0.02) ***
Boys^{a} **(Restricted Sample)**	7457 (48.3)	37.55 (0.85) ***	29.40 (1.13) ***	39.69 (0.97) ***	0.09 (0.02) ***

Table S A-5: Association between gender and volumes of sedentary activity as defined by Evenson cut points for both restricted (as presented in the chapter) and unrestricted sample sizes. Differences in mean, variability and skewness estimated by GAMLSS, a = samples after restriction for complete cases of for parental education, BMI, and country. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

		NO distribution		**BCCG distribution**	
Gender	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**[b]
Girls (ref) **(Unrestricted Sample)**	9117 (52.1)	368.9	98.7	363.1	0.57
Girls[a] **(Restricted Sample)**	7377 (52.2)	365.86	99.39	359.64	0.54
Boys **(Unrestricted Sample)**	8387 (47.9)	-5.11 (0.41) ***	-1.00 (1.07)	-5.29 (0.45) ***	-0.01 (0.04)
Boys[a] **(Restricted Sample)**	6763 (47.8)	-5.01 (0.46) ***	-1.34 (1.19)	-5.15 (0.51) ***	0.01 (0.05)

Table S A-6: Association between gender and volumes of light activity as defined by Evenson cut points for both restricted (as presented in the chapter) and unrestricted sample sizes. Differences in mean, variability and skewness estimated by GAMLSS, a = samples after restriction for complete cases of for parental education, BMI, and country. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

Gender	N (%)	NO distribution Mean % Difference (SE)	 SD % Difference (SE)	BCCG distribution Median % Difference (SE)	 Skewness[b]
Girls (ref) (Unrestricted Sample)	9804 (48.3)	358.6	78.3	361.1	1.29
Girls[a] (Restricted Sample)	7998 (51.7)	361.93	77.73	364.43	1.29
Boys (Unrestricted Sample)	9176 (48.3)	1.06 (0.32) ***	2.02 (1.03) *	1.12 (0.33) ***	0.02 (0.05)
Boys[a] (Restricted Sample)	7463 (48.3)	0.82 (0.34) *	2.36 (1.14) *	0.90 (0.36) *	0.03 (0.05)

A.4.2 Models adjusted for season or for ethnicity.

Table S A-7: Association between gender and counts per minute for the restricted model adjusted for gender, country, BMI (z-score) and parental education (as presented in the chapter) and two further models, one additionally adjusted for season, one additionally adjusted for ethnicity. *Differences in mean, variability and skewness estimated by GAMLSS NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.*

		NO distribution		**BCCG distribution**	
Gender	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
Girls **(Adjusted Model)**	7377 (52.2)	546.70	187.86	520.18	0.48
Girls **(Adjusted Model + Season)**	5359 (52.6)	658.50	183.50	634.58	0.62
Girls **(Adjusted Model + Ethnicity)**	5750 (52.0)	556.77	184.10	544.22	0.50
Boys **(Adjusted Model)**	6091 (47.8)	19.74 (0.58) ***	17.24 (1.19) ***	21.14 (0.63) ***	0.17 (0.03) ***
Boys **(Adjusted Model + Season)**	4832 (47.4)	18.70 (0.64) ***	17.10 (1.40) ***	19.62 (0.69) ***	0.16 (0.04) ***
Boys **(Adjusted Model + Ethnicity)**	5300 (48.0)	20.58 (0.68) ***	20.20 (1.35) ***	21.69 (0.73) ***	0.17 (0.03) ***

Table S A-8: Association between gender and volumes of moderate to vigorous physical activity for the restricted model adjusted for gender, country, BMI (z-score) and parental education (as presented in the chapter) and two further models, one additionally adjusted for season, one additionally adjusted for ethnicity. Differences in mean, variability and skewness estimated by GAMLSS NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

Gender	**N (%)**	**NO distribution**		**BCCG distribution**	
		Mean % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**[b]
Girls (Adjusted Model)	7996 (51.7)	53.00	22.16	47.27	0.55
Girls[a] **(Adjusted Model + Season)**	5822 (52.4)	52.80	22.30	48.67	0.60
Girls (Adjusted Model + Ethnicity)	6165 (51.5)	31.76	22.43	30.087	0.53
Boys (Adjusted Model)	7457 (48.3)	37.59 (0.79) ***	30.29 (1.14) ***	40.34 (0.92) ***	0.08 (0.02) ***
Boys (Adjusted Model + Season)	5280 (47.6)	35.37 (0.86) ***	29.22 (1.35) ***	36.48 (0.98) ***	0.11 (0.02) ***
Boys (Adjusted Model + Ethnicity)	5816 (48.5)	39.22 (0.96) ***	31.45 (1.30) ***	42.08 (1.11) ***	0.08 (0.02) ***

*Table S A-9: Association between gender and volumes of sedentary activity for the restricted model adjusted for gender, country, BMI (z-score) and parental education (as presented in the chapter) and two further models, one additionally adjusted for season, one additionally adjusted for ethnicity. Differences in mean, variability and skewness estimated by GAMLSS NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.*

Gender	N (%)	NO distribution Mean % Difference (SE)	 SD % Difference (SE)	BCCG distribution Median % Difference (SE)	 Skewness[b]
Girls (Adjusted Model)	7377 (52.2)	354.35	94.67	346.52	0.70
Girls[a] (Adjusted Model + Season)	5359 (52.6)	302.20	87.47	299.38	0.59
Girls (Adjusted Model + Ethnicity)	5750 (52.0)	356.37	93.32	355.06	0.71
Boys (Adjusted Model)	6763 (47.8)	-5.04 (0.44) ***	-1.58 (1.19)	-5.18 (0.46) ***	-0.01 (0.05)
Boys (Adjusted Model + Season)	4832 (47.2)	-5.03 (0.50) ***	-1.14 (1.40)	-5.02 (0.54) ***	0.05 (0.06)
Boys (Adjusted Model + Ethnicity)	5300 (48.0)	-4.88 (0.49) ***	-0.01 (1.35)	-4.92 (0.52) ***	0.02 (0.05)

Table S A-10: Association between gender and volumes of activity for the restricted model adjusted for gender, country, BMI (z-score) and parental education (as presented in the chapter) additionally adjusted for wear time. Differences in mean, variability and skewness estimated by GAMLSS NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

Model	**Gender**	**NO distribution**		**BCCG distribution**	
		Mean % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^b**
CPM (Adjusted + Wear Time)	**Girls**	922.57	186.65	912.23	0.5
	Boys	19.9 (0.58)	17.52 (1.19) ***	21.43 (0.58) ***	0.18 (0) **
MVPA (Adjusted + Wear Time)	**Girls**	37.79	22.28	33.42	-0.57
	Boys	37.51 (0.79)	29.98 (1.14) ***	40.12 (0.8) ***	-0.08 (0) ***
Sedentary (Adjusted + Wear Time)	**Girls**	84.55	2.14 (1.19)	90.71	-1.51
	Boys	-5.9 (0.38) ***	2.14 (1.19)	-6.13 (0.38) ***	0.08 (0) **
Light (Adjusted + Wear Time)	**Girls**	224.5	71.01	215.96	-1.65
	Boys	0.5 (0.31)	0.03 (1.14)	0.3 (0.28)	-0.01 (0.4) ***

A.4.3 Moderate activity

Boys observed a higher daily volume of moderate activity than girls (Girls: 31.19 min/day, Boys: 43.07 min/day) (Figure S A-10), estimated to be a 30% greater in the adjusted model (Table S A-11). The median for both genders was approximately 1min30 less than the mean, resulting in a similar percentage difference between the median boy and girl (Table S A-11). Boys additionally had a wider distribution of values, marked by a lower peak density and a greater standard deviation (Girls:15.73, Boys: 20.35) (Figure S A-10), mirrored by an estimated 25% increased for boys in the adjusted GAMLSS model (Table S A-11). Both samples were positively skewed, with the sample of boys slightly less skewed in both the unadjusted and adjusted model, though the difference is minimal (Table S A-11).

A.4.4 Vigorous activity

While both genders reported low daily volumes of vigorous activity, boys reported slightly higher values (Girls: 11.71 min/day, Boys: 19.30 min/day) (Figure S A-11) estimated to be 50% greater in the adjusted model (Table S A-12). In addition to a greater mean volume, boys showed a wider distribution of values, noted by a greater standard deviation (Girls:10.29, Boys: 14.42) (Figure S A-11) estimated to be 34% greater in boys. Both distributions appear to be strongly positively skewed, with the strength of skewness stronger for girls than boys (Girls: 1.75, Boys: 1.16).

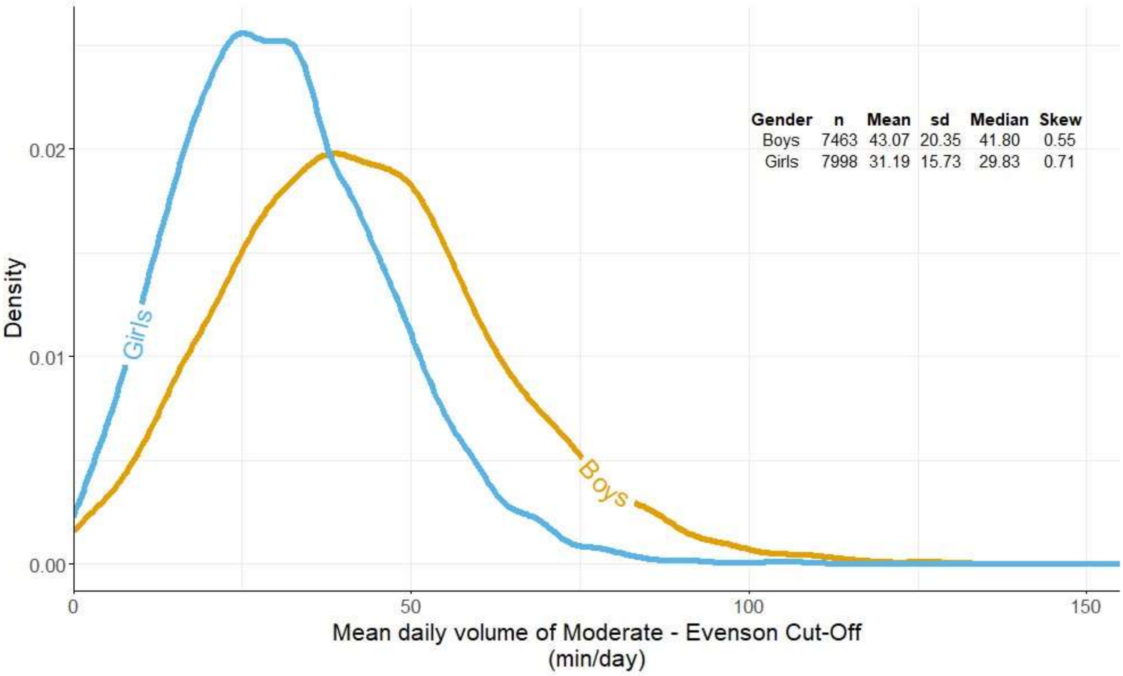


Figure S A-10: Density plot of moderate activity as defined by Evenson cut points. Each line representing a gender. Plot is censored at 150 min/day to show centre of distribution.

Table S A-11: Association between gender and moderate activity as defined by Evenson cut points. Differences in mean, variability and skewness estimated by GAMLSS, n=, a = adjusted for parental education, BMI, and country. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

Risk factor	**N (%)**	**NO distribution**		**BCCG distribution**	**Skewness**^{b}
		Mean % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	
Girls (ref) **Unadjusted**	7998 (51.7)	31.19	15.72	29.56	0.64
Boys **(Unadjusted Difference)**	7463 (48.3)	32.27 (0.79) ***	25.76 (1.14) ***	33.59 (0.88) ***	0.07 (0.02) **
Boys^{a} **(Adjusted Difference)**	7463 (48.3)	32.38 (0.76) ***	26.54 (1.14) ***	34.32 (0.84) ***	0.07 (0.02) *

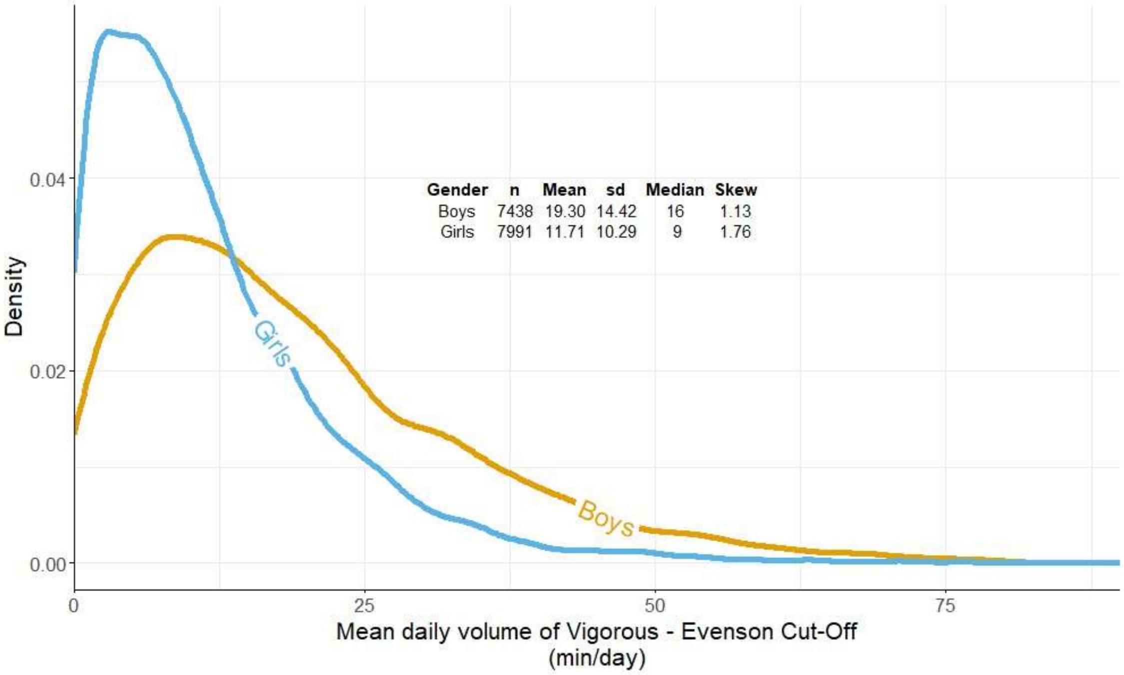


Figure S A-11: Density plot of vigorous activity as defined by Evenson cut points. Each line representing a gender. Plot is censored at 75 min/day to show centre of distribution.

Table S A-12: Association between gender and vigorous activity as defined by Evenson cut points. Differences in mean, variability and skewness estimated by GAMLSS, n=, a = adjusted for parental education, BMI, and country. NO: normal distribution. SD: standard deviation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

Risk factor	**N (%)**	**NO distribution** **Mean** % Difference (SE)	 **SD** % Difference (SE)
Girls (ref) **Unadjusted**	7991 (51.8)	11.71	10.28
Boys **(Unadjusted Difference)**	7438 (48.2)	49.93 (1.31) ***	33.78 (1.14) ***
Boys[a] **(Adjusted Difference)**	7438 (48.2)	49.81 (1.22) ***	33.66 (1.14) ***

Table S A-13: Association between gender and volumes of light physical activity for the restricted model adjusted for gender, country, BMI (z-score) and parental education (as presented in the chapter) and two further models, one additionally adjusted for season, one additionally adjusted for ethnicity. Differences in mean, variability and skewness estimated by GAMLSS NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution, values closer to 1 represent less skew). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001.

Gender	N (%)	NO distribution Mean % Difference (SE)	 SD % Difference (SE)	BCCG distribution Median % Difference (SE)	 Skewness[b]
Girls **(Adjusted Model)**	7998 (51.7)	379.15	75.18	373.09	1.39
Girls[a] **(Adjusted Model + Season)**	5823 (52.4)	374.28	69.72	372.54	1.56
Girls **(Adjusted Model + Ethnicity)**	6167 (51.4)	360.92	76.59	366.84	1.37
Boys **(Adjusted Model)**	7463 (48.3)	0.88 (0.33) **	3.26 (1.14) **	0.87 (0.35) *	-0.02 (0.06)
Boys **(Adjusted Model + Season)**	5286 (47.6)	0.45 (0.36)	2.86 (1.34) *	0.46 (0.37)	-0.08 (0.07)
Boys **(Adjusted Model + Ethnicity)**	5822 (48	1.37 (0.39) ***	3.47 (1.30) **	1.26 (0.41) **	-0.02 (0.06)

*Table S A-14: Descriptive results of for each activity measure, presented by gender. * Indicates that the sample used excludes participants from Brazil and those with over 16hr of activity per day. See section 3.2.4 for detail. To reduce the effect of outliers on measures of skewness and kurtosis, some measures have been restricted. 1: Sample has been restricted to individuals who have less than 1500 cpm. 2: Sample has been restricted to individuals who recorded less than 200 min/day of moderate activity. 3: Sample has been restricted to individuals who recorded less than 75 min/day of vigorous activity. 4: Sample has been restricted to individuals who recorded less than 200 min/day of moderate-to-vigorous activity.*

	Gender	Sample Size (n)	Mean	Std Dev	Median	Skew
***Counts per minute[1]**	Girls	9118	530.37	198.06	507.00	0.74
	Boys	8388	641.45	234.62	619.00	0.51
MVPA[4]	Girls	9802	43.48	24.03	40.25	0.82
	Boys	9164	61.76	31.72	58.30	0.61
***Sedentary**	Girls	9131	368.77	98.84	362.60	0.37
	Boys	8411	350.17	97.92	344.40	0.39
Light	Girls	9804	358.58	78.28	361.00	-0.21
	Boys	9176	362.42	79.88	365.00	-0.24
Moderate[2]	Girls	9802	31.60	15.99	30.14	0.68
	Boys	9164	42.57	20.18	41.00	0.53
Vigorous[3]	Girls	9797	11.83	10.35	9.17	1.75
	Boys	9139	18.98	14.34	15.71	1.16

Appendix B Appendix to Chapter 4: Cross-national comparisons of physical activity in youth; an exploration of location scale and shape in the International Children's Accelerometry Database.

B.1 Sensitivity Analyses: Unadjusted Models

Table S B-1: Unadjusted association between country of study and physical activity as measured by counts per minute. Differences in mean, variability and skew estimated by GAMLSS. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^b**
United Kingdom (ref)	4761 (34.46)	587.9	185.85	567.91	0.29
Australia	2287 (16.55)	19.47 (0.77) ***	13.6 (1.8) ***	19.67 (0.77) ***	-0.03 (0.06) ***
Denmark	1148 (8.31)	-8.76 (1.28) ***	27.82 (2.12) ***	-10.03 (1.25) ***	0.29 (0.05)
Estonia	584 (4.23)	6.21 (1.7) ***	28.67 (3.1) ***	5.18 (1.69) **	0.15 (0.08) ***
Norway	355 (2.57)	18.49 (2.16) ***	41.66 (3.89) ***	21.12 (1.82) ***	1.03 (0.1)
Portugal	617 (4.47)	-0.41 (1.67)	22.58 (3.03) ***	0.49 (1.59)	0.41 (0.08)
Switzerland	116 (0.84)	23.53 (2.64) ***	11.28 (6.64)	25.36 (2.61) ***	0.31 (0.25) ***
USA	3949 (28.58)	-13.19 (0.82) ***	17.32 (1.52) ***	-15.9 (0.81) ***	0.03 (0.04) ***

Table S B-2: Unadjusted association between country of study and moderate to vigorous activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Country	**N (%)**	**NO distribution**		**BCCG distribution**	
		Mean % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^{b}**
United Kingdom (ref)	4785 (43.19)	55.62	27.03	51.76	0.4
Australia	2372 (21.41)	11.32 (1.09) ***	-6.26 (1.78) ***	13.99 (1.08) ***	0.07 (0.04) ***
Brazil	455 (4.11)	-38.19 (3.09) ***	-10.28 (3.47) **	-43.77 (3.07) ***	0.03 (0.06) ***
Denmark	1488 (13.43)	-17.46 (1.82) ***	11.56 (2.1) ***	-2125.79 (3.73) ***	0.1 (0.02) *
Estonia	591 (5.33)	8.73 (2.48) ***	25.99 (3.08) ***	6.89 (2.43) **	0.11 (0.05) **
Norway	367 (3.31)	22.87 (2.85) ***	31.34 (3.83) ***	22.71 (2.82) ***	0.34 (0.07)
Portugal	637 (5.75)	-2.89 (2.52)	19.9 (2.98) ***	-5.78 (2.46) *	0.18 (0.05)
Switzerland	385 (2.49)	28.56 (2.13) ***	7.65 (3.75) *	31.78 (2.11) ***	0.11 (0.1) ***
USA	4351 (28.2)	55.62	27.03	51.76	0.4

Table S B-3: Unadjusted association between country of study and sedentary activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
United Kingdom (ref)	4761 (34.46)	356.59	72.75	356.42	0.98
Australia	2287 (16.55)	-17.34 (0.64) ***	12.04 (1.8) ***	-18.81 (0.63) ***	-0.37 (0.08) ***
Denmark	1148 (8.31)	8.61 (0.87) ***	51.51 (2.12) ***	5.7 (0.87) ***	-0.57 (0.08) ***
Estonia	584 (4.23)	-3.5 (1.32) **	38.42 (3.1) ***	-5.78 (1.31) ***	-0.45 (0.11) ***
Norway	355 (2.57)	-8.48 (1.7) ***	35.02 (3.89) ***	-14.57 (1.48) ***	-1.44 (0.15) ***
Portugal	617 (4.47)	0.7 (1.2)	35.2 (3.03) ***	-0.75 (1.17)	-0.33 (0.12) ***
Switzerland	116 (0.84)	-10.13 (2.75) ***	26.55 (6.64) ***	-13.75 (2.77) ***	-0.82 (0.24) ***
USA	3949 (28.58)	7.75 (0.54) ***	39.49 (1.52) ***	6.91 (0.52) ***	-0.19 (0.07) ***

*Table S B-4: Unadjusted association between country of study and light activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.*

Country	N (%)	NO distribution Mean % Difference (SE)	 SD % Difference (SE)	BCCG distribution Median % Difference (SE)	 Skewness^{b}
United Kingdom (ref)	4785 (43.16)	360.75	61.2	361.56	1.15
Australia	2372 (21.4)	4.39 (0.41) ***	-2.45 (1.78)	4.26 (0.39) ***	-0.08 (0.12) ***
Brazil	455 (4.1)	-0.49 (1.12)	31.07 (3.47) ***	-2.09 (1.11)	-0.66 (0.16) ***
Denmark	1491 (13.45)	-2.23 (0.75) **	45.14 (2.1) ***	-0.97 (0.64)	0.36 (0.1)
Estonia	594 (5.36)	10.27 (0.88) ***	29.75 (3.08) ***	11.06 (0.79) ***	0.33 (0.17) ***
Norway	367 (3.31)	7.28 (1.16) ***	31.79 (3.83) ***	9.43 (0.81) ***	1.85 (0.22)
Portugal	637 (5.75)	2.57 (0.96) **	34.96 (2.98) ***	4.01 (0.81) ***	0.55 (0.15)
Switzerland	385 (2.49)	20.84 (0.81) ***	9.08 (3.75) *	20.68 (0.78) ***	-0.1 (0.26) ***
USA	4352 (28.19)	360.75	61.2	361.56	1.15

Table S B-5: Unadjusted association between country of study and moderate activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Country	**N (%)**	**NO distribution**		**BCCG distribution**	
		Mean % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^{b}**
United Kingdom (ref)	4785 (43.16)	39.27	16.87	37.37	0.48
Australia	2372 (21.4)	9.16 (0.96) ***	-9.13 (1.78) ***	11.18 (0.95) ***	0.08 (0.05) ***
Brazil	455 (4.1)	-24.26 (3.03) ***	14.27 (3.47) ***	-31.59 (3) ***	-0.05 (0.06) ***
Denmark	1491 (13.45)	-18.17 (1.69) ***	16.33 (2.1) ***	-23.36 (1.66) ***	0.04 (0.04) ***
Estonia	594 (5.36)	10.07 (2.53) ***	43.07 (3.08) ***	4.86 (2.47) *	-0.02 (0.06) ***
Norway	367 (3.31)	18.28 (2.66) ***	32.71 (3.83) ***	17.54 (2.61) ***	0.3 (0.07)
Portugal	637 (5.75)	1.98 (2.28)	27.38 (2.98) ***	-0.4 (2.21)	0.17 (0.05)
Switzerland	385 (2.49)	28.65 (1.81) ***	3.31 (3.75)	31.86 (1.76) ***	0.22 (0.12) ***
USA	4352 (28.19)	39.27	16.87	37.37	0.48

Table S B-6: Unadjusted association between country of study and vigorous activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS. NO: normal distribution. SD: standard deviation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Country	N (%)	NO distribution	
		Mean	SD
		% Difference (SE)	% Difference (SE)
United Kingdom (ref)	4775 (43.17)	16.22	12.28
Australia	2371 (21.43)	17.03 (1.74) ***	2.73 (1.78)
Brazil	455 (4.11)	-81.77 (5.04) ***	-49.14 (3.47) ***
Denmark	1487 (13.44)	-14.45 (2.65) ***	6.24 (2.1) **
Estonia	589 (5.32)	7 (3.63)	17.51 (3.09) ***
Norway	364 (3.29)	31.06 (3.96) ***	26.95 (3.84) ***
Portugal	637 (5.76)	-14.8 (3.81) ***	4.95 (2.98)
Switzerland	384 (2.49)	28.2 (3.47) ***	12.21 (3.75) **
USA	4344 (28.2)	16.22	12.28

B.2 Sensitivity Analyses: Unadjusted Models in unrestricted samples

Table S B-7: Unadjusted association between country of study and physical activity as measured by counts per minute. Differences in mean, variability and skew estimated by GAMLSS, n=, b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Risk factor	N (%)	NO distribution		BCCG distribution	
		Mean	**SD**	**Median**	**Skewness^b**
United Kingdom (ref)	6657 (38.0)	584.36	189.33	564.36	584.36
Australia	2452 (14.0)	19.62 (0.72) ***	11.93 (1.67) ***	19.8 (0.72) ***	19.62 (0.72) ***
Denmark	1582 (9.0)	-8.59 (1.22) ***	26.37 (1.98) ***	-10.17 (1.2) ***	-8.59 (1.22) ***
Estonia	647 (3.7)	6.61 (1.6) ***	26.3 (2.91) ***	5.56 (1.59) ***	6.61 (1.6) ***
Norway	375 (2.1)	18.34 (2.12) ***	40.18 (3.75) ***	20.7 (1.78) ***	18.34 (2.12) ***
Portugal	1157 (6.6)	-3.55 (1.16) **	9.74 (2.25) ***	-2.63 (1.12) *	-3.55 (1.16) **
Switzerland	166 (0.9)	20.69 (2.42) ***	15.39 (5.56) **	22.38 (2.38) ***	20.69 (2.42) ***
USA	4468 25.5	-12.93 (0.76) ***	16.72 (1.37) ***	-15.75 (0.76) ***	-12.93 (0.76) ***

Table S B-8: Unadjusted association between country of study and moderate to vigorous physical activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS, n=, b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Risk factor	**N (%)**	**NO distribution**		**BCCG distribution**	
		Mean	**SD**	**Median**	**Skewness**[b]
United Kingdom (ref)	6692 (35.28)	55.41	27.34	51.52	55.41
Australia	2542 (13.4)	11.26 (1.01)	-7.76 (1.65) ***	13.94 (1) ***	11.26 (1.01)
Brazil	456 (2.4)	-37.83 (3.07) ***	-11.55 (3.42) ***	-43.32 (3.05) ***	-37.83 (3.07) ***
Denmark	1633 (8.61)	-16.74 (1.71) ***	10.36 (1.95) ***	-719.68 (3.17) ***	-16.74 (1.71) ***
Estonia	655 (3.45)	9.06 (2.32)	24.2 (2.89) ***	7.43 (2.28) **	9.06 (2.32)
Norway	387 (2.04)	22.24 (2.79)	30.53 (3.7) ***	-1169.47 (7.2) ***	22.24 (2.79)
Portugal	1183 (6.24)	-7.15 (1.82) ***	10.88 (2.23) ***	-9.12 (1.77) ***	-7.15 (1.82) ***
Switzerland	500 (2.64)	26.28 (1.92)	7.23 (3.28) *	30.25 (1.87) ***	26.28 (1.92)
USA	4918 (25.93)	-27.81 (1.13) ***	2.64 (1.33) *	-2840.36 (2.1) ***	-27.81 (1.13) ***

Table S B-9: Unadjusted association between country of study and sedentary activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS, n=, b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Risk factor	N (%)	NO distribution		BCCG distribution	
		Mean	SD	Median	Skewness[b]
United Kingdom (ref)	6656 (38.03)	359.44	77.85	357.49	0.77
Australia	2452 (14.01)	-17.53 (0.62) ***	6.46 (1.67) ***	-18.57 (0.61) ***	-0.18 (0.07) ***
Denmark	1582 (9.04)	8.48 (0.83) ***	45.56 (1.98) ***	6.36 (0.83) ***	-0.3 (0.07) ***
Estonia	647 (3.7)	-3.8 (1.24) **	31.52 (2.91) ***	-5.5 (1.23) ***	-0.23 (0.1) ***
Norway	375 (2.14)	-8.64 (1.67) ***	29.93 (3.75) ***	-14.39 (1.45) ***	-1.24 (0.15) ***
Portugal	1157 (6.61)	1.86 (0.79) *	18.13 (2.25) ***	1.52 (0.78)	-0.04 (0.1) ***
Switzerland	166 (0.95)	-8.11 (2.3) ***	22.73 (5.56) ***	-10.57 (2.33) ***	-0.45 (0.2) ***
USA	4468 (25.53)	7.16 (0.5) ***	33.08 (1.37) ***	6.79 (0.48) ***	0 (0.06) ***

Table S B-10: Unadjusted association between country of study and light activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS, n=, b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Risk factor	**N (%)**	**NO distribution**		**BCCG distribution**	
		Mean	**SD**	**Median**	**Skewness**^{b}
United Kingdom (ref)	6696 (35.28)	356.33	65.07	357.75	356.33
Australia	2542 (13.39)	5.44 (0.39)	-7.73 (1.65) ***	5.19 (0.37) ***	5.44 (0.39)
Brazil	456 (2.4)	0.68 (1.11)	25.02 (3.42) ***	-1.12 (1.11)	0.68 (1.11)
Denmark	1636 (8.62)	-1.48 (0.72) ***	40.03 (1.95) ***	-0.58 (0.62)	-1.48 (0.72) ***
Estonia	659 (3.47)	10.82 (0.84)	23.38 (2.89) ***	11.41 (0.75) ***	10.82 (0.84)
Norway	387 (2.04)	8.04 (1.14)	26.21 (3.7) ***	9.89 (0.8) ***	8.04 (1.14)
Portugal	1184 (6.24)	1.84 (0.67)	19.35 (2.23) ***	2.64 (0.59) ***	1.84 (0.67)
Switzerland	500 (2.63)	20.38 (0.75)	7.3 (3.28) *	20.09 (0.73) ***	20.38 (0.75)
USA	4920 (25.92)	-2.99 (0.43) ***	31.92 (1.33) ***	-2.98 (0.4) ***	-2.99 (0.43) ***

*Table S B-11: Unadjusted association between country of study and moderate activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS, n=, b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.*

Risk factor	N (%)	NO distribution		BCCG distribution	
		Mean	SD	Median	Skewness^{b}
United Kingdom (ref)	6696 (35.28)	38.99	17.26	37.02	38.99
Australia	2542 (13.39)	9.46 (0.89)	-12.04 (1.65) ***	11.75 (0.88) ***	9.46 (0.89)
Brazil	456 (2.4)	-23.56 (3) ***	11.89 (3.42) ***	-30.62 (2.98) ***	-23.56 (3) ***
Denmark	1636 (8.62)	-16.88 (1.59) ***	14.36 (1.95) ***	-21.75 (1.56) ***	-16.88 (1.59) ***
Estonia	659 (3.47)	10.11 (2.38)	39.8 (2.89) ***	5.19 (2.33) *	10.11 (2.38)
Norway	387 (2.04)	17.93 (2.62)	31.05 (3.7) ***	16.85 (2.58) ***	17.93 (2.62)
Portugal	1184 (6.24)	1.22 (1.66)	21.41 (2.23) ***	-0.57 (1.61)	1.22 (1.66)
Switzerland	500 (2.63)	27.53 (1.66)	4.24 (3.28)	31.47 (1.57) ***	27.53 (1.66)
USA	4920 (25.92)	-28.16 (1.01) ***	2.56 (1.33)	-33.24 (1) ***	-28.16 (1.01) ***

Table S B-12: Unadjusted association between country of study and vigorous activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS, n=, b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Risk factor	**N (%)**	**NO distribution**	
		Mean	**SD**
United Kingdom (ref)	6676	16.28	12.32
Australia	2541	16.16 (1.61)	2.86 (1.65)
Brazil	456	-82.24 (5) ***	-49.54 (3.42) ***
Denmark	1632	-15.07 (2.48) ***	5.57 (1.95) **
Estonia	653	8.39 (3.4)	18.45 (2.9) ***
Norway	384	29.88 (3.85)	26.5 (3.71) ***
Portugal	1184	-28.43 (2.89) ***	-6.49 (2.23) **
Switzerland	499	23.33 (3.13)	10.72 (3.28) **
USA	4911	-26.65 (1.72) ***	2.94 (1.33) *

B.3 Sensitivity Analyses: Models Adjusted for Season

Table S B-13: Adjusted association between country of study and physical activity as measured by counts per minute. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and Season (accounting for hemispheric differences), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
United Kingdom (ref)	4761	537.65	171.07	521.59	0.39
Australia	2287	20.88 (0.79) ***	17.68 (1.8) ***	21.25 (0.78) ***	-0.16 (0.07) ***
Denmark	1448	-5.91 (1.25) ***	32.77 (2.12) ***	-6.75 (1.19) ***	0.27 (0.06)
Estonia	584	7.69 (1.6) ***	30.76 (3.1) ***	6.98 (1.57) ***	0.18 (0.09) **
Norway	355	17.42 (2.07) ***	45.57 (3.89) ***	20 (1.72) ***	1.05 (0.11)
Portugal	617	-1.64 (1.71)	25.61 (3.03) ***	0.4 (1.58)	0.54 (0.09)
Switzerland	116	18.54 (2.59) ***	17.26 (6.64) **	20.33 (2.58) ***	0.2 (0.25) ***

Table S B-14: Adjusted association between country of study and volumes of moderate to vigorous physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and Season (accounting for hemispheric differences), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. **** = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$. Values are reported as % and SE.***

Country	N (%)	NO distribution		BCCG distribution	
		Mean % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^{b}**
United Kingdom (ref)	4784	47.35	24.42	45.34	0.51
Australia	2372	11.52 (1.06) ***	-4.44 (1.78) *	14.66 (1.06) ***	0.01 (0.05) ***
Brazil	455	-45.91 (3.03) ***	-3.88 (3.47)	-51.9 (3.06) ***	-0.06 (0.06) ***
Denmark	1488	-16.09 (1.73) ***	17.23 (2.1) ***	-20.48 (1.69) ***	0.06 (0.04) ***
Estonia	591	8.19 (2.31) ***	30.38 (3.08) ***	6.83 (2.27) **	0.07 (0.06) ***
Norway	367	19.21 (2.64) ***	34.8 (3.83) ***	19.61 (2.58) ***	0.31 (0.07)
Portugal	637	-5.12 (2.47) *	22.89 (2.98) ***	-8.64 (2.4) ***	0.18 (0.05)
Switzerland	385	26.24 (1.94) ***	6.6 (3.75)	29.22 (1.94) ***	0.08 (0.11) ***

Table S B-15: Adjusted association between country of study and volumes of sedentary activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and Season (accounting for hemispheric differences), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Country	**N (%)**	**NO distribution**		**BCCG distribution**	
		Mean % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^{b}**
United Kingdom (ref)	4761	361.72	70.18	360.26	0.94
Australia	2287	-18.61 (0.67) ***	14.38 (1.8) ***	-19.92 (0.66) ***	-0.35 (0.08) ***
Denmark	1448	5.98 (0.87) ***	53.86 (2.12) ***	3.35 (0.88) ***	-0.53 (0.08) ***
Estonia	584	-5.23 (1.31) ***	40.58 (3.1) ***	-7.35 (1.31) ***	-0.43 (0.11) ***
Norway	355	-8.64 (1.67) ***	36.34 (3.89) ***	-14.79 (1.43) ***	-1.51 (0.16) ***
Portugal	617	2.15 (1.31)	37.49 (3.03) ***	0.69 (1.29)	-0.33 (0.12) ***
Switzerland	116	-7.54 (2.81) **	31.82 (6.64) ***	-10.47 (2.81) ***	-0.71 (0.24) ***

Table S B-16: Adjusted association between country of study and volumes of light physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and Season (accounting for hemispheric differences), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^{b}**
United Kingdom (ref)	4785	356.82	60.49	358.07	1.17
Australia	2372	4.8 (0.44) ***	-2.33 (1.78)	4.68 (0.42) ***	-0.06 (0.12) ***
Brazil	455	-2.56 (1.14) *	30.42 (3.47) ***	-4.25 (1.13) ***	-0.67 (0.17) ***
Denmark	1491	-0.77 (0.75)	45.33 (2.1) ***	0.33 (0.65)	0.33 (0.1)
Estonia	594	11.31 (0.89) ***	30.12 (3.08) ***	12.18 (0.79) ***	0.39 (0.17) ***
Norway	367	7.47 (1.15) ***	31.69 (3.83) ***	9.58 (0.81) ***	1.84 (0.22)
Portugal	637	2.02 (1.04)	36.06 (2.98) ***	3.61 (0.87) ***	0.65 (0.15)
Switzerland	385	20.01 (0.85) ***	12.92 (3.75) ***	19.91 (0.82) ***	-0.17 (0.26) ***

Table S B-17: Adjusted association between country of study and volumes of moderate physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and Season (accounting for hemispheric differences), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. **** = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$. Values are reported as % and SE.***

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**[b]
United Kingdom (ref)	4785	34.16	15.31	33.35	0.6
Australia	2372	9.35 (0.94) ***	-7.62 (1.78) ***	11.53 (0.93) ***	0 (0.05) ***
Brazil	455	-30.85 (2.94) ***	20.09 (3.47) ***	-39.03 (2.96) ***	-0.16 (0.06) ***
Denmark	1491	-16.33 (1.61) ***	21.93 (2.1) ***	-20.99 (1.57) ***	-0.02 (0.04) ***
Estonia	594	10.53 (2.38) ***	47.66 (3.08) ***	5.76 (2.3) *	-0.07 (0.06) ***
Norway	367	15.56 (2.49) ***	36.32 (3.83) ***	15.28 (2.39) ***	0.25 (0.08)
Portugal	637	-0.23 (2.27)	31.18 (2.98) ***	-2.82 (2.16)	0.15 (0.06) *
Switzerland	385	26.52 (1.69) ***	4.16 (3.75)	29.96 (1.63) ***	0.25 (0.13) ***

Table S B-18: Adjusted association between country of study and volumes of vigorous physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and Season (accounting for hemispheric differences), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)
United Kingdom (ref)	4775	13.14	11.42
Australia	2371	17.35 (1.71) ***	4.68 (1.78) **
Brazil	455	-92.12 (5.04) ***	-43.18 (3.47) ***
Denmark	1487	-14.7 (2.54) ***	10.57 (2.1) ***
Estonia	589	4.37 (3.41)	20.28 (3.09) ***
Norway	364	24.88 (3.73) ***	29.52 (3.84) ***
Portugal	637	-16.18 (3.71) ***	5.53 (2.98)
Switzerland	384	25.91 (3.08) ***	7.85 (3.75) *

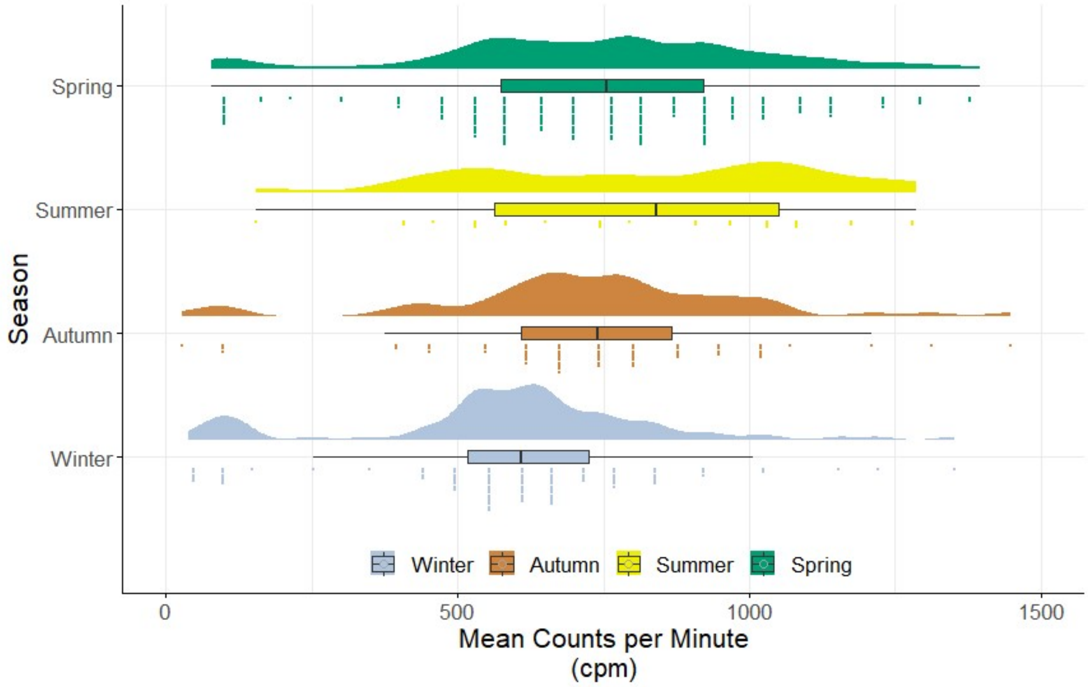


Figure S B-1: Rainfall plot of mean counts per minute in the Norwegian sample. Density and Bar plot are grouped by meteorological season. Points are clustered into bins of 50cpm. Of note, are the number of individuals below 250cpm, which form the bulk of individuals in the low cluster of individuals.

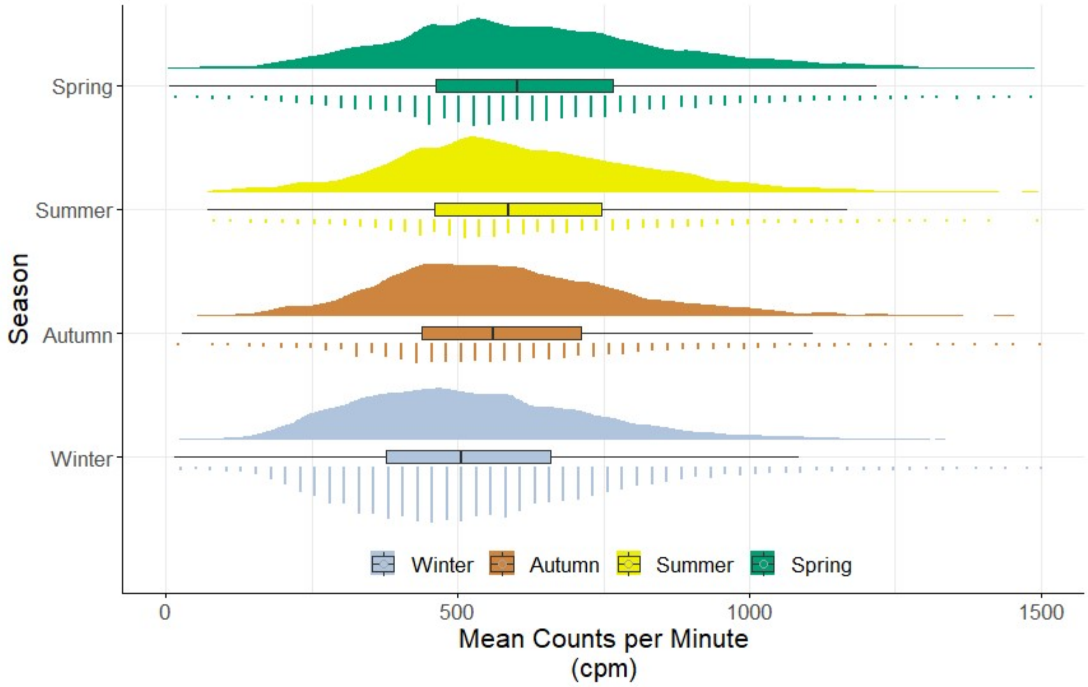


Figure S B-2: Rainfall plot of mean counts per minute in all samples. Density and Bar plot are grouped by meteorological season. Points are clustered into bins of 25cpm.

B.4 Sensitivity Analyses: Models adjusted for ethnicity.

Table S B-19: Adjusted association between country of study and physical activity as measured by counts per minute. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and ethnicity (White or Other), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^{b}**
United Kingdom (ref)	4474	549.86	175.49	532.45	0.37
Denmark	1098	0.88 (1.28)	29.94 (2.38) ***	2.33 (1.19)	0.44 (0.07)
Estonia	581	5.72 (1.63) ***	30.09 (3.12) ***	4.54 (1.61) **	0.14 (0.09) ***
Norway	341	16.21 (2.2) ***	46.94 (3.97) ***	18.92 (1.82) ***	1.03 (0.1)
Portugal	607	-3.01 (1.73)	22.54 (3.06) ***	-2.38 (1.64)	0.45 (0.09)
USA	3949	-13.8 (1.15) ***	18.39 (1.54) ***	-16.39 (1.12) ***	0 (0.05) ***

Table S B-20: Adjusted association between country of study and volumes of moderate to vigorous physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and ethnicity (White or Other), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
United Kingdom (ref)	4492	50.13	24.8	47.55	0.49
Brazil	451	-46.92 (3.1) ***	-5.61 (3.49)	-52.17 (3.15) ***	-0.06 (0.06) ***
Denmark	1121	-9.31 (1.85) ***	19.1 (2.36) ***	-12.05 (1.81) ***	0.14 (0.04)
Estonia	588	7.48 (2.36) **	30.58 (3.1) ***	5.79 (2.32) *	0.07 (0.06) ***
Norway	353	17.57 (2.8) ***	37.04 (3.91) ***	18.82 (2.71) ***	0.3 (0.07)
Portugal	625	-6.13 (2.52) *	21.32 (3.02) ***	-10.67 (2.49) ***	0.16 (0.05)
USA	4351	-32.42 (1.63) ***	3.23 (1.5) *	-39.78 (1.61) ***	-0.02 (0.03) ***

Table S B-21: Adjusted association between country of study and volumes of sedentary activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and ethnicity (White or Other), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
United Kingdom (ref)	4474	364.66	71.72	362.09	0.99
Denmark	1098	-2.36 (0.93) *	34.15 (2.38) ***	-5.12 (0.92) ***	-0.69 (0.1) ***
Estonia	581	-2.92 (1.31) *	38.75 (3.12) ***	-5.3 (1.3) ***	-0.45 (0.11) ***
Norway	341	-7.55 (1.75) ***	37.18 (3.97) ***	-13.76 (1.52) ***	-1.49 (0.16) ***
Portugal	607	3.91 (1.3) **	35.49 (3.06) ***	2.4 (1.26)	-0.31 (0.12) ***
USA	3949	6.5 (0.78) ***	40.17 (1.54) ***	5.98 (0.76) ***	-0.22 (0.07) ***

Table S B-22: Adjusted association between country of study and volumes of light physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and ethnicity (White or Other), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**[b]
United Kingdom (ref)	4493	367.92	61.04	368.2	1.17
Brazil	451	-2.12 (1.17)	30.12 (3.49) ***	-3.69 (1.15) **	-0.62 (0.17) ***
Denmark	1124	5.77 (0.71) ***	32.8 (2.36) ***	7.3 (0.59) ***	0.6 (0.13)
Estonia	591	9.87 (0.89) ***	30.07 (3.09) ***	10.61 (0.8) ***	0.28 (0.17) ***
Norway	353	6.32 (1.19) ***	31.7 (3.91) ***	8.42 (0.83) ***	1.86 (0.22)
Portugal	625	1.43 (1.06)	35.39 (3.02) ***	2.71 (0.9) **	0.59 (0.15)
USA	4352	-5.01 (0.66) ***	36.43 (1.5) ***	-4.82 (0.61) ***	-0.07 (0.08) ***

Table S B-23: Adjusted association between country of study and volumes of moderate physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and ethnicity (White or Other), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
United Kingdom (ref)	4493	35.89	15.55	34.75	0.58
Brazil	451	-31.13 (3.01) ***	18.41 (3.49) ***	-38.97 (3.04) ***	-0.14 (0.06) ***
Denmark	1124	-8.99 (1.71) ***	23.28 (2.36) ***	-11.79 (1.65) ***	0.11 (0.05) *
Estonia	591	9.63 (2.42) ***	47.46 (3.09) ***	4.49 (2.35)	-0.07 (0.06) ***
Norway	353	14.16 (2.63) ***	38.03 (3.91) ***	14.25 (2.52) ***	0.25 (0.08)
Portugal	625	-1.74 (2.32)	29.48 (3.02) ***	-5.24 (2.25) *	0.15 (0.06) *
USA	4352	-32.43 (1.49) ***	5.17 (1.5) ***	-38.14 (1.45) ***	-0.05 (0.03) ***

Table S B-24: Adjusted association between country of study and volumes of vigorous physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and ethnicity (White or Other), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)
United Kingdom (ref)	4484	14.12	11.52
Brazil	451	-95.76 (5.16) ***	-45.05 (3.49) ***
Denmark	1120	-9.3 (2.75) ***	13.39 (2.36) ***
Estonia	586	4.23 (3.44)	20.51 (3.11) ***
Norway	350	21.93 (3.95) ***	32.26 (3.92) ***
Portugal	625	-16.25 (3.75) ***	4.76 (3.02)
USA	4344	-32.69 (2.49) ***	1.03 (1.51)

B.5 Sensitivity Analyses: Models Adjusted for wear-time

Table S B-25: Adjusted association between country of study and physical activity as measured by counts per minute. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and wear time, reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

	NO distribution		**BCCG distribution**	
Country	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^{b}**
United Kingdom (ref)	105.59	64.37	111.76	0.91
Brazil	-2.54 (0.47) ***	-18.04 (1.8) ***	-3.58 (0.5) ***	-0.17 (0.1)
Denmark	4.28 (0.61)	25.32 (2.12) ***	1.61 (0.64) *	-0.42 (0.11) ***
Estonia	-11.14 (1.01) ***	24.59 (3.1) ***	-12.74 (1.06) ***	-0.37 (0.14) **
Norway	-0.07 (1.65) ***	44.57 (3.89) ***	-6.15 (1.35) ***	-1.71 (0.17) ***
Portugal	0.32 (1.04)	29.37 (3.03) ***	-1.27 (1.09)	-0.79 (0.13) ***
USA	-0.21 (1.84) ***	-0.29 (6.64)	-1.12 (1.85)	-0.07 (0.35)

Table S B-26: Adjusted association between country of study and volumes of moderate to vigorous physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and wear time. Reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Risk factor	**NO distribution**		**BCCG distribution**	
	Mean	**SD**	**Median**	**Skewness^{b}**
United Kingdom (ref)	29.83	24.47	28.43	0.49
Australia	0.14 (1.11)	-3.43 (1.78)	4.02 (1.08) ***	0 (0.05)
Denmark	-58.95 (3.21) ***	-4.93 (3.47)	-64.49 (3.3) ***	-0.06 (0.06) ***
Estonia	-16.38 (1.59) ***	10.81 (2.1) ***	-22.17 (1.61) ***	0.09 (0.04) *
Norway	5.78 (2.33)	31.48 (3.08) ***	6.3 (2.3) **	0.06 (0.06) ***
Portugal	7.65 (2.7)	36.48 (3.83) ***	8.06 (2.67) **	0.3 (0.07)
Switzerland	-9.31 (2.33) ***	19.88 (2.98) ***	-12.35 (2.26) ***	0.22 (0.06)
USA	-6.27 (2.39) ***	9.48 (3.75) *	-2.15 (2.42)	-0.05 (0.1)

Table S B-27: Adjusted association between country of study and volumes of sedentary behaviour. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and wear time. Reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

	NO distribution		**BCCG distribution**	
Country	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness**^{b}
United Kingdom (ref)	105.59	64.37	111.76	0.91
Brazil	-2.54 (0.47) ***	-18.04 (1.8) ***	-3.58 (0.5) ***	-0.17 (0.1)
Denmark	4.28 (0.61)	25.32 (2.12) ***	1.61 (0.64) *	-0.42 (0.11) ***
Estonia	-11.14 (1.01) ***	24.59 (3.1) ***	-12.74 (1.06) ***	-0.37 (0.14) **
Norway	-0.07 (1.65) ***	44.57 (3.89) ***	-6.15 (1.35) ***	-1.71 (0.17) ***
Portugal	0.32 (1.04)	29.37 (3.03) ***	-1.27 (1.09)	-0.79 (0.13) ***
USA	-0.21 (1.84) ***	-0.29 (6.64)	-1.12 (1.85)	-0.07 (0.35)

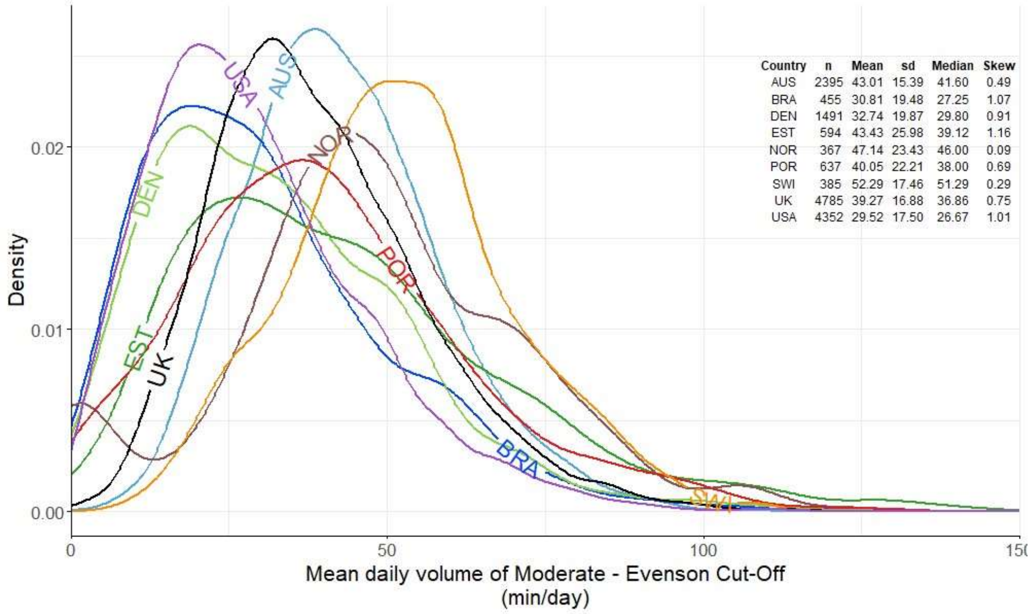
Table S B-28: Adjusted association between country of study and volumes of light intensity physical activity. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean) and wear time. Reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Risk factor	**NO distribution**		**BCCG distribution**	
	Mean	**SD**	**Median**	**Skewness^b**
United Kingdom (ref)	196.76	55.56	185.88	1.21
Australia	-2.71 (0.39) ***	-9.18 (1.78) ***	-1.23 (0.37) ***	-0.07 (0.14) ***
Denmark	-24.9 (1.09) ***	26.17 (3.47) ***	-29.47 (1.09) ***	-0.82 (0.19) ***
Estonia	-2.25 (0.59) ***	29.81 (2.1) ***	-2.66 (0.54) ***	0.42 (0.12)
Norway	8.77 (0.72)	18.1 (3.08) ***	8.94 (0.67) ***	0.42 (0.2) *
Portugal	-1.92 (1.09) ***	34.82 (3.83) ***	1.04 (0.74)	2.07 (0.24)
Switzerland	-0.91 (0.85) ***	27.38 (2.98) ***	0.54 (0.73)	0.78 (0.18)
USA	-17.13 (0.94) ***	16.05 (3.75) ***	-16.81 (0.98) ***	-1.1 (0.25) ***

B.6 Moderate activity.

The British sample engaged in a mean volume of moderate activity of 39min/day with the scale of difference with other samples varying from -28% to +28% (Table S B-29). Mirroring patterns observed in MVPA, the volume of moderate activity was lowest in the US (Mean: 30min/day) and Brazilian samples (Mean: 31min/day), estimated at as a reduction of 29% for both samples compared to the UK in adjusted models (Figure S B-3 & Table S B-29). As with MVPA positive differentials compared to the UK for volumes of moderate activity of were observed for the same four nations: Australia (Mean: 43min/day, +9%), Estonia (Mean: 43min/day, +10%), Norway (Mean: 47 min/day, +15%), and Switzerland: (Mean: 52 min/day, +28%) (Figure S B-3 & Table S B-29). For all samples, the median volume of moderate activity is between 1 and 4 minutes lower than their respective mean, reflecting a positive skew in all samples, ranging from weak (Norway: +0.09) to strong (Estonia: +1.16) (Figure S B-3).

The British and Australian samples observed the lowest deviation of individuals (UK: ±17min/day, Australia: ±15min/day) (Figure S B-3), with the Australian sample the only group to return a negative differential with the UK (-10%) (Table S B-29). Scales of difference with the UK approach or exceeded 20% in samples from Brazil (+19%), Denmark (+21%), Estonia (+47%), Norway (+37%) and Portugal (+29%) (Table S B-29).



Country	n	Mean	sd	Median	Skew
AUS	2395	43.01	15.39	41.60	0.49
BRA	455	30.81	19.48	27.25	1.07
DEN	1491	32.74	19.87	29.80	0.91
EST	594	43.43	25.98	39.12	1.16
NOR	367	47.14	23.43	46.00	0.09
POR	637	40.05	22.21	38.00	0.69
SWI	385	52.29	17.46	51.29	0.29
UK	4785	39.27	16.88	36.86	0.75
USA	4352	29.52	17.50	26.67	1.01

Figure S B-3: Density plot of moderate activity as defined by Evenson cut points. Each line representing a different country in the study. Plot is censored at 150 min/day to show centre of distribution.

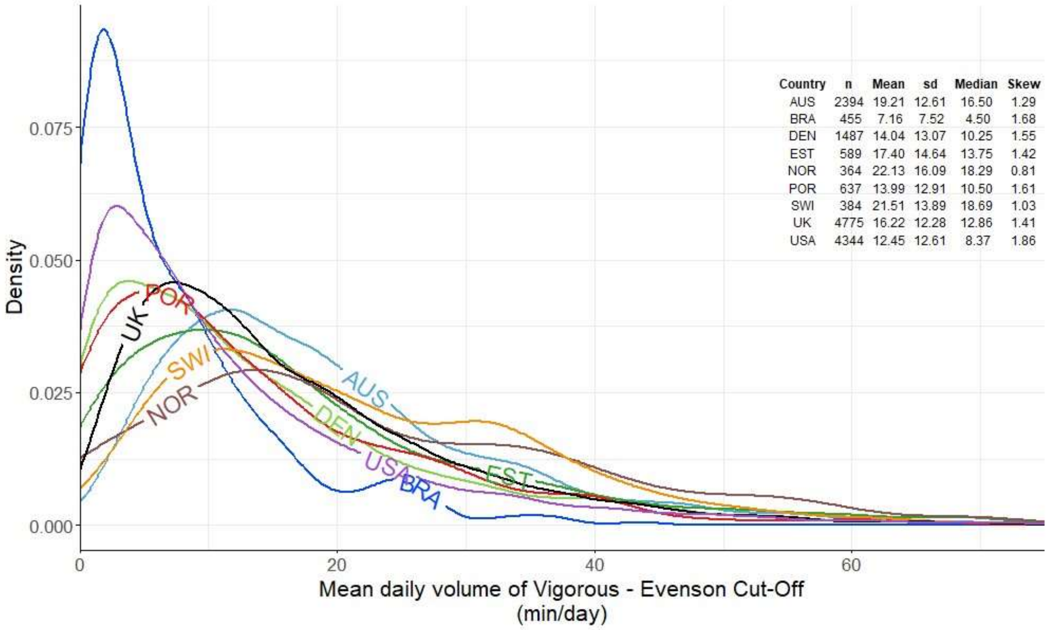
Table S B-29: Adjusted association between country of study and moderate activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. b = Skewness is estimated as the Box-Cox power (that is, the power required to transform the outcome to a normal distribution). BCCG: Box-Cox Cole and Green distribution: SD: standard deviation. CoV: coefficient of variation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

		NO distribution		**BCCG distribution**	
Country	**N (%)**	**Mean** % Difference (SE)	**SD** % Difference (SE)	**Median** % Difference (SE)	**Skewness^b**
United Kingdom (ref)	4785 (43.16)	34.35	15.57	33.43	0.58
Australia	2372 (21.4)	8.86 (0.9)	-9.98 (1.78) ***	10.39 (0.9) ***	0.01 (0.05) ***
Brazil	455 (4.1)	-28.75 (2.94) ***	18.91 (3.47) ***	-36.94 (2.96) ***	-0.15 (0.06) ***
Denmark	1491 (13.45)	-18.07 (1.61) ***	21.23 (2.1) ***	-22.88 (1.57) ***	-0.01 (0.04) ***
Estonia	594 (5.36)	9.82 (2.4)	47.1 (3.08) ***	4.72 (2.33) *	-0.07 (0.06) ***
Norway	367 (3.31)	15.08 (2.55)	36.98 (3.83) ***	15.06 (2.44) ***	0.26 (0.08)
Portugal	637 (5.75)	-1.82 (2.21) ***	29 (2.98) ***	-5.18 (2.14) *	0.15 (0.06) *
Switzerland	385 (2.49)	27.59 (1.64)	2.26 (3.75)	31.02 (1.59) ***	0.24 (0.13) ***
USA	4352 (28.19)	-28.72 (1.05) ***	5.42 (1.48) ***	-34.99 (1.04) ***	-0.05 (0.03) ***

B.7 Vigorous activity.

The lowest mean volume of vigorous activity is seen in the Brazilian sample (Mean = 7 min/day), with Norway returning the highest mean value of 22min/day (Figure S B-4). Compared to the British sample (Mean: 16min/day), Estonia (+5%), Australia (+18%), Norway (+24%) and Switzerland (+27%) saw positive differentials (Table S B-30). The largest difference was observed with the Brazilian sample (-90%), which was the single largest difference observed for any intensity. The Danish (-16%), Portuguese (-18%) and US samples (-23%) also observed negative differentials with the UK sample (Table S B-30).

The lowest spread of individuals was observed for the Brazilian sample (SD: 7.52min/day) (Figure S B-4) and was the only sample with a narrower distribution that the UK (-44%) (Table S B-30). Compared to the UK (SD: 12.28min/day) all other samples observed increases in their standard deviation, up to a maximum increase of +31% for the Norwegian sample, though only a further two observed a margin of differentiation greater than +10% (Denmark: +11%, Estonia: +20%) (Table S B-30). Though an estimate of skew could not be established with a BCCG transformed GAMLSS, all samples were strongly positively skewed (Figure S B-4).



Country	n	Mean	sd	Median	Skew
AUS	2394	19.21	12.61	16.50	1.29
BRA	455	7.16	7.52	4.50	1.68
DEN	1487	14.04	13.07	10.25	1.55
EST	589	17.40	14.64	13.75	1.42
NOR	364	22.13	16.09	18.29	0.81
POR	637	13.99	12.91	10.50	1.61
SWI	384	21.51	13.89	18.69	1.03
UK	4775	16.22	12.28	12.86	1.41
USA	4344	12.45	12.61	8.37	1.86

Figure S B-4: Density plot of vigorous activity as defined by Evenson cut points. Each line representing a different country in the study.

Table S B-30: Adjusted association between country of study and vigorous activity defined by Evenson cut points, measured as minutes per day. Differences in mean, variability and skew estimated by GAMLSS. Adjusted for parental education, BMI (Z-Score), gender, and age (centred to mean), reference is UK, a girl, neither parent in receipt of further education, age and BMI Z-Score are centred. NO: normal distribution. SD: standard deviation. GAMLSS: Generalized Additive Models for Location, Scale and Shape. SE, standard error. * = p<0.05, ** = p<0.01, *** = p<0.001. Values are reported as % and SE.

Country	**N (%)**	**NO distribution**	
		Mean	**SD**
		% Difference (SE)	% Difference (SE)
United Kingdom (ref)	4775 (43.17)	12.64	11.5
Australia	2371 (21.43)	17.57 (1.64)	3.55 (1.78) *
Brazil	455 (4.11)	-89.99 (5.02) ***	-43.55 (3.47) ***
Denmark	1487 (13.44)	-15.88 (2.52) ***	10.52 (2.1) ***
Estonia	589 (5.32)	4.6 (3.41)	20.33 (3.09) ***
Norway	364 (3.29)	24.26 (3.82)	31.07 (3.84) ***
Portugal	637 (5.76)	-17.64 (3.58) ***	4.46 (2.98)
Switzerland	384 (2.49)	27.16 (2.98)	6.69 (3.75)
USA	4344 (28.2)	-22.53 (1.74) ***	1.96 (1.48)

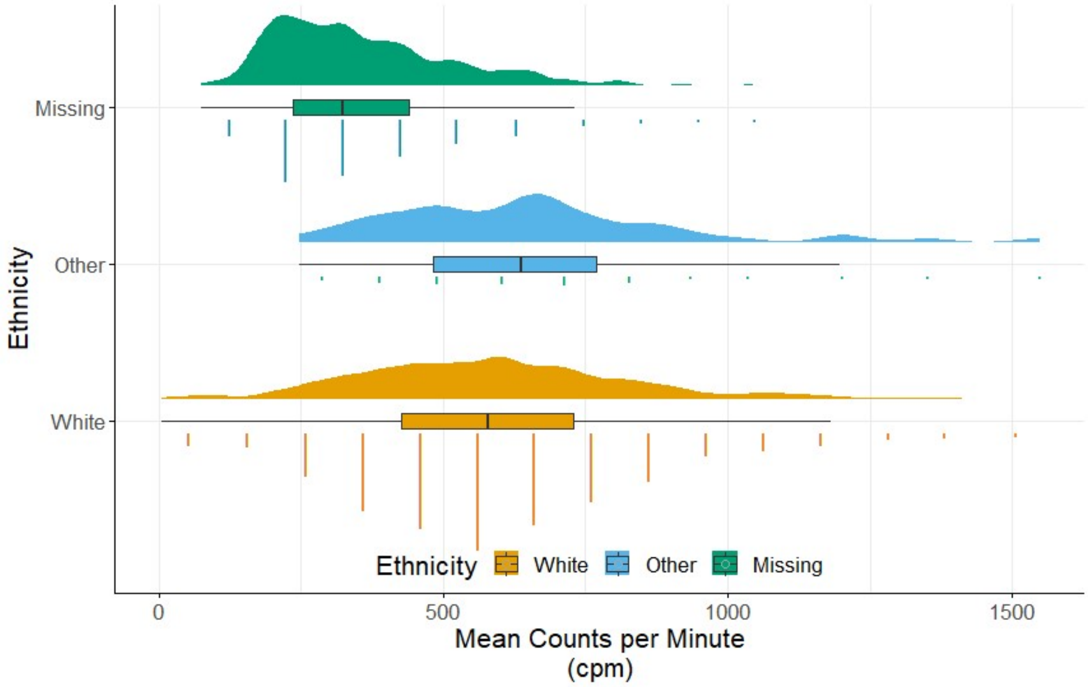


Figure S B-5: Distribution of Individuals in the Danish sample for Counts per Minute, grouped by Ethnicity. Ethnicity is classified as "White", "Other" or as "Missing". Missing individuals were removed from sensitivity analysis including ethnicity. plot is censored at 1,750 cpm to centre of distribution.

Appendix C Appendix to Chapter 5: Physical Activity in the BaYaka Hunter-Gatherers

C.1 Literature Reviewed

Table S C-1: Literature reviewed pertaining to physical activity in subsistence populations. All studies were published before 28/7/23. Ordered by year of publication.* To avoid potential confusion between wrist and waist, hip is used throughout to indicate the wearing of an accelerometer around the lower torso. Key for used abbreviations: GPS = Global Positioning System, DLW = Doubly Labelled Water, HR = Heart Rate Monitor, P/L = Pregnant or Lactating, NA = No Association, ND = No Difference, ↑ = Positively Associated, ↓ = Negatively Associated, PA = Physical Activity, EE = Energy Expenditure, TEE = Total Energy Expenditure, PAEE = Physically Active Energy Expenditure, PAL = Physical Activity Level, MPA = Moderate Intensity Physical Activity, VPA = Vigorous Physical Activity

Author(s)	**Study Location**	**Population**	**Study Size (N)**	**Age Range**	**Sex**	**PA Measurement***	**Factors**	**Directionality**	**Reported PA Exceeds WHO recommendations**	**Includes Children?**
Katzmarzyk et al., 1994[398]	Russia	Evenki & Keto	46 (26% Female)	16-47	M & F	HR, Respirometry	Sex	ND in sex for PAEE		
Kashiwazaki et al., 1995[399]	Bolivia	Aymara	23 (65% Female)	4-65	M & F	DLW	Sex, Age	NA for Sex, Adults ↑ PAEE than younger ages		✓
Panter-Brick, 1996[479]	Nepal	Tamang	20	20-55	M	Direct Observation, Respirometry	Sex	Male ↑ PA (Compared to reference Values)	✓	

Author(s)	Study Location	Population	Study Size (N)	Age Range	Sex	PA Measurement*	Factors	Directionality	Reported PA Exceeds WHO recommendations	Includes Children?
Yamauchi, Sato and Kawamura, 2000[393]	Cameroon	Baka	4 (50% Female)	20-40	M & F	Direct Observation, HR	Sex, Age	Younger ↑ PA than Older		
Esparza et al., 2000[480]	Mexico & USA	Pima Indians	80 (43% Female)	Mean: 37 +- 12y	M & F	DLW, Gas Exchange	Market Integration	NA for Market Integration and TEE	✓	
Yamauchi, Umezaki and Ohtsuka, 2001[225]	Papua New Guinea	Huli	27 Rural (44% Female), 29 Urban (48% Female)	20-59	M & F	Direct Observation, HR	Sex, Market Intergration	Female in Urban ↓ PA	✓	
Madimenos et al., 2011[128]	Ecuador	Shuar	49 (53% Female)	14-66	M & F	Accelerometry (Hip)	Sex, Maternal Status	M with P/L partner ↑ PA		✓
Pontzer et al., 2012[79]	Tanzania	Hadza	30 (56% Female)	18-75	M & F	DLW, GPS, Respirometry	Sex, Maternal Status	M ↑ Daily Distance	✓	

Author(s)	**Study Location**	**Population**	**Study Size (N)**	**Age Range**	**Sex**	**PA Measurement***	**Factors**	**Directionality**	**Reported PA Exceeds WHO recommendations**	**Includes Children?**
Christensen et al., 2012[401]	Kenya	Maasai, Kamba, Luo	1099 (61% Female)	17-68	M & F	Accelerometry (Hip), HR	Sex, Age	NA for Accelerometry. M ↑PAEE. Age ↓ PAEE	✓	
Ojiambo et al., 2013[394]	Kenya	~Rural	30 (50% Female)	10-17	M & F	Accelerometry (Hip), DLW	Sex	M ↑ PA by Accelerometry. ND in EE by sex	✓	✓
Gurven et al., 2013[127]	Bolivia	Tsimane	34 (32% Female)	20-60+	M & F	Accelerometry (Hip), Direct Observation, HR	Sex, Age	PA peaked at late 20s for M, early teens for F. ND in PAL by sex	✓	
Hagino and Yamauchi, 2014[129]	Cameroon	BaYaka	44 (36% Female)	2-16	M & F	Accelerometer (Hip), GPS	Sex, Age	ND in PA or daily steps.	✓	✓
Pontzer et al., 2015[87]	Tanzania	Hadza	41 (63% Female)	18-80	M & F	DLW, GPS	Sex, Age, Maternal Status	M ↑ Daily Steps. Age ↓ Steps. NA with sex or Age and PA	✓	
Samson et al., 2017[397]	Tanzania	Hadza	33 (64% Female)	18-65	M & F	Accelerometry (Wrist)	Sex, Age	ND for sex. Age ↓ Sleep		

Author(s)	**Study Location**	**Population**	**Study Size (N)**	**Age Range**	**Sex**	**PA Measurement***	**Factors**	**Directionality**	**Reported PA Exceeds WHO recommendations**	**Includes Children?**
Raichlen et al., 2017[130]	Tanzania	Hadza	46 (59% Female)	6-80	M & F	HR	Sex, Age	ND for Sex. Age ↑ PA	✓	✓
Froehle et al., 2019[229]	Tanzania	Hadza	76 (57% Female)	2-16	M & F	Direct Observation	Sex, Age	F ↑ MPA. Adolescent ↑ MPA. M ↑ PAL		✓
Lew-Levy et al., 2019[202]	Tanzania & Congo	Hadza & Bayaka	Hadza = 46 (41% Female), Bayaka = 65 (48% Female)	3-18	M & F	Direct Observation	Sex, Age	Age ↓ Play.		✓
Sayre et al., 2019[481]	Kenya	Pokot	40 (43% Female)	14-78	M & F	Accelerometry (Wrist)	Sex, Age	M ↑ PA. Age ↓ PA	✓	✓
Sarma et al., 2020[126]	Congo	BaYaka	37 (54% Female)	22-62	M & F	Accelerometry (Wrist), Direct Observation, HR	Sex	F ↑ MVPA.	✓	

Author(s)	**Study Location**	**Population**	**Study Size (N)**	**Age Range**	**Sex**	**PA Measurement***	**Factors**	**Directionality**	**Reported PA Exceeds WHO recommendations**	**Includes Children?**
Raichlen et al., 2020[131]	Tanzania	Hadza	28 (43% Female)	18-61	M & F	Accelerometry (Thigh)	Sex, Age	ND for Sex, NA for Age	✓	
Sayre et al., 2020[224]	Tanzania	Hadza & Pokot	Hadza = 53 (45% Female), Pokot = 39 (44% Female)	4-77	M & F	Accelerometry (Wrist)	Sex, Age	ND in sex for Hadza. M ↑ PA in Pokot. Age ↓ MVPA	✓	✓
Wood et al., 2021[396]	Tanzania	Hadza	179 (49% Female)	2-84	M & F	GPS	Sex, Age	M ↑ Daily Steps, peak 35 for M. F peak in teens, decline during childrearing ages, increase beyond 40		✓
Ocobock et al., 2021[482]	Finland	~Reindeer Herders	24 (21% Female)	20-64	M & F	DLW	Sex	NA in Sex, TEE: 4k kcal, PAL: 2.3		

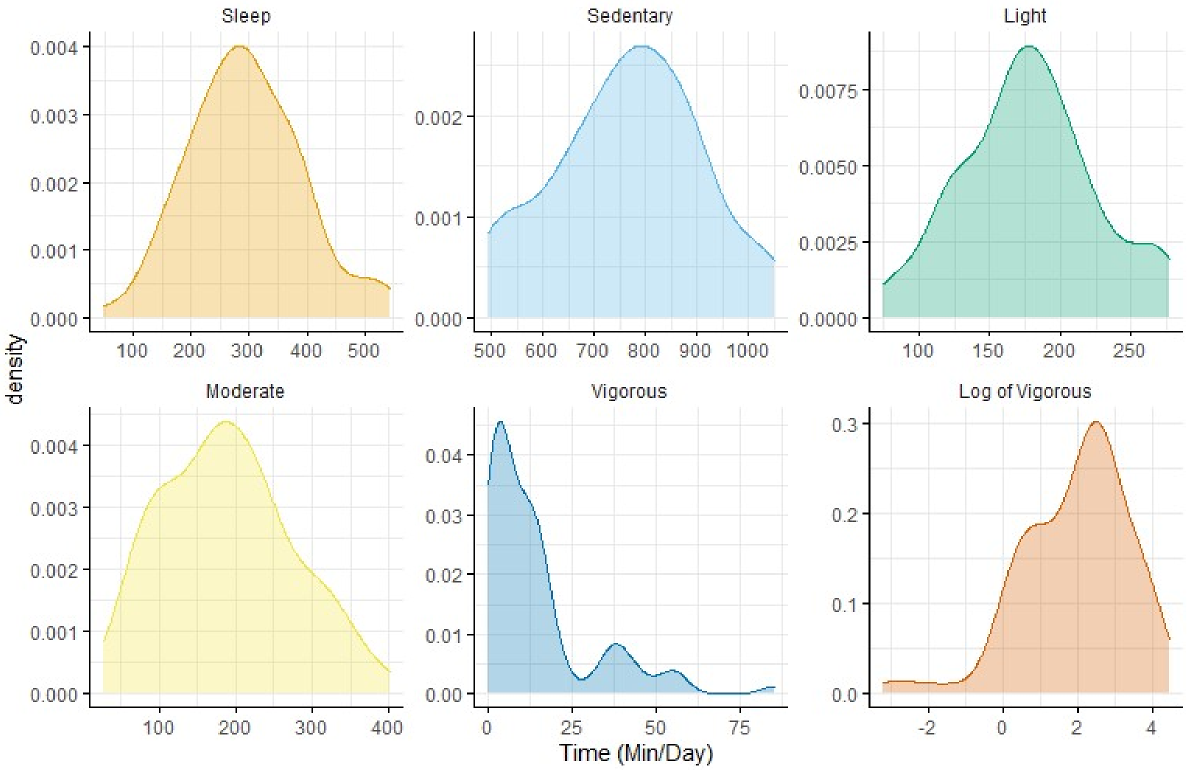


Figure S C-1:Density plot of distribution of time spent in each intensity for all individuals in the study. Owing to the skewed distribution of vigorous activity it is replotted following a log transformation at base 10.

C.2 Supplemental Analyses

C.2.1 Unadjusted and Adjusted models for Gender

Table S C-2: Unadjusted and Adjusted linear model results for the fixed effect of gender with the outcome variable of the mean acceleration (mg ENMO)

	Mean Acceleration [Unadjusted]					**Mean Acceleration [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
(Intercept)	41.09	37.19 – 45.00	-0.21	-0.46 – 0.04	**<0.001**	42.54	38.16 – 46.92	-0.12	-0.40 – 0.16	**<0.001**
Gender [Man]	8.57	2.28 – 14.86	0.55	0.15 – 0.95	**0.008**	8.54	2.28 – 14.80	0.55	0.15 – 0.95	**0.008**
Age Category [Middle Adult]						-4.74	-11.37 – 1.90	-0.30	-0.73 – 0.12	0.160
Observations	96					96				
R^2 / R^2 adjusted	0.072 / 0.062					0.092 / 0.072				

Table S C-3: Unadjusted and Adjusted linear model results for the fixed effect of gender with the outcome variable of mean daily volume of sedentary activity (min/day)

	Volume of Sedentary Activity [Unadjusted]					**Volume of Sedentary Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
(Intercept)	769.91	732.78 – 807.04	-0.02	-0.28 – 0.24	**<0.001**	744.74	704.17 – 785.32	-0.20	-0.48 – 0.09	**<0.001**
Gender [Man]	7.79	-52.02 – 67.60	0.05	-0.36 – 0.47	0.797	8.43	-49.53 – 66.40	0.06	-0.35 – 0.46	0.773
Age Category [Middle Adult]						82.50	21.06 – 143.94	0.58	0.15 – 1.01	**0.009**
Observations	96					96				
R^2 / R^2 adjusted	0.001 / -0.010					0.072 / 0.052				

Table S C-4: Unadjusted and Adjusted linear model results for the fixed effect of gender with the outcome variable of mean daily volume of light activity (min/day)

	Volume of Light Activity [Unadjusted]					**Volume of Light Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
(Intercept)	186.09	174.55 – 197.63	0.18	-0.07 – 0.43	**<0.001**	181.27	168.37 – 194.18	0.07	-0.21 – 0.36	**<0.001**
Gender [Man]	-21.14	-39.73 – -2.56	-0.46	-0.87 – -0.06	**0.026**	-21.02	-39.46 – -2.58	-0.46	-0.87 – -0.06	**0.026**
Age Category [Middle Adult]						15.78	-3.76 – 35.32	0.35	-0.08 – 0.77	0.112
Observations	96					96				
R^2 / R^2 adjusted	0.051 / 0.041					0.077 / 0.057				

Table S C-5: Unadjusted and Adjusted linear model results for the fixed effect of Gender with the outcome variable of mean daily volume of moderate activity (min/day)

	Volume of Moderate Activity [Unadjusted]					**Volume of Moderate Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
(Intercept)	176.31	154.76 – 197.85	-0.10	-0.36 – 0.15	**<0.001**	188.29	164.46 – 212.12	0.04	-0.24 – 0.33	**<0.001**
Gender [Man]	22.35	-12.36 – 57.05	0.27	-0.15 – 0.68	0.204	22.04	-12.01 – 56.09	0.26	-0.14 – 0.67	0.202
Age Category [Middle Adult]						-39.28	-75.37 – -3.19	-0.47	-0.90 – -0.04	**0.033**
Observations	96					96				
R^2 / R^2 adjusted	0.017 / 0.007					0.064 / 0.044				

Table S C-6: Unadjusted and Adjusted linear model results for the fixed effect of gender with the outcome variable of mean daily volume of vigorous activity (min/day)

	Log$_{10}$Volume of Vigorous Activity [Unadjusted]					**Log$_{10}$Volume of Vigorous Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	0.73	0.57 – 0.88	-0.18	-0.43 – 0.08	**<0.001**	0.82	0.64 – 0.99	-0.03	-0.31 – 0.25	**<0.001**
Gender [Man]	0.28	0.03 – 0.53	0.46	0.05 – 0.87	**0.027**	0.28	0.04 – 0.52	0.46	0.06 – 0.86	**0.025**
Age Category [Middle Adult]						-0.29	-0.55 – -0.03	-0.48	-0.90 – -0.06	**0.027**
Observations	96					96				
R^2 / R^2 adjusted	0.051 / 0.041					0.100 / 0.081				

C.2.2 Unadjusted and Adjusted models for Age Category

Table S C-7: Unadjusted and Adjusted linear model results for the fixed effect of age group with the outcome variable of the mean acceleration (mg ENMO)

	Mean Acceleration [Unadjusted]					**Mean Acceleration [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	45.85	42.25 – 49.45	0.14	-0.10 – 0.38	**<0.001**	43.21	39.17 – 47.25	-0.04	-0.30 – 0.23	**<0.001**
Age Category [Child]	-0.49	-7.12 – 6.14	-0.03	-0.47 – 0.41	0.883	-1.98	-8.56 – 4.60	-0.13	-0.57 – 0.30	0.552
Age Category [Middle Adult]	-4.81	-11.36 – 1.74	-0.32	-0.75 – 0.11	0.148	-4.75	-11.16 – 1.65	-0.31	-0.74 – 0.11	0.144
Age Category [Older Adult]	-12.56	-22.55 – -2.57	-0.83	-1.49 – -0.17	**0.014**	-12.64	-22.41 – -2.88	-0.83	-1.48 – -0.19	**0.012**
Gender [Man]						6.80	1.69 – 11.91	0.45	0.11 – 0.79	**0.009**
Observations	134					134				
R^2 / R^2 adjusted	0.055 / 0.033					0.103 / 0.075				

Table S C-8: Unadjusted and Adjusted linear model results for the fixed effect of age group with the outcome variable of mean daily volume of sedentary activity (min/day)

	Volume of Sedentary Activity [Unadjusted]					**Volume of Sedentary Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	748.02	715.78 – 780.25	-0.22	-0.45 – 0.01	**<0.001**	740.11	703.08 – 777.14	-0.28	-0.54 – -0.01	**<0.001**
Age Category [Child]	10.14	-49.23 – 69.51	0.07	-0.35 – 0.50	0.736	5.68	-54.63 – 65.99	0.04	-0.39 – 0.47	0.853
Age Category [Middle Adult]	82.43	23.78 – 141.07	0.59	0.17 – 1.01	**0.006**	82.60	23.90 – 141.31	0.59	0.17 – 1.01	**0.006**
Age Category [Older Adult]	143.75	54.31 – 233.18	1.03	0.39 – 1.67	**0.002**	143.50	53.97 – 233.04	1.03	0.39 – 1.67	**0.002**
Gender [Man]						20.37	-26.45 – 67.20	0.15	-0.19 – 0.48	0.391
Observations	134					134				
R^2 / R^2 adjusted	0.108 / 0.088					0.113 / 0.086				

Table S C-9: Unadjusted and Adjusted linear model results for the fixed effect of age group with the outcome variable of mean daily volume of light activity (min/day)

	Volume of Light Activity [Unadjusted]					**Volume of Light Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	173.12	161.70 – 184.54	-0.14	-0.38 – 0.10	**<0.001**	180.95	168.09 – 193.81	0.03	-0.25 – 0.30	**<0.001**
Age Category [Child]	6.53	-14.51 – 27.56	0.14	-0.31 – 0.58	0.540	10.95	-9.99 – 31.90	0.23	-0.21 – 0.67	0.303
Age Category [Middle Adult]	15.97	-4.81 – 36.74	0.34	-0.10 – 0.78	0.131	15.79	-4.60 – 36.18	0.33	-0.10 – 0.76	0.128
Age Category [Older Adult]	24.51	-7.18 – 56.19	0.52	-0.15 – 1.19	0.128	24.75	-6.35 – 55.84	0.52	-0.13 – 1.18	0.118
Gender [Man]						-20.20	-36.46 – -3.94	-0.43	-0.77 – -0.08	**0.015**
Observations	134					134				
R^2 / R^2 adjusted	0.029 / 0.007					0.072 / 0.044				

Table S C-10: Unadjusted and Adjusted linear model results for the fixed effect of age group with the outcome variable of mean daily volume of moderate activity (min/day)

	Volume of Moderate Activity [Unadjusted]					**Volume of Moderate Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	196.84	178.48 – 215.20	0.31	0.08 – 0.54	**<0.001**	189.68	168.68 – 210.69	0.22	-0.04 – 0.48	**<0.001**
Age Category [Child]	-44.89	-78.70 – -11.07	-0.56	-0.98 – -0.14	**0.010**	-48.93	-83.13 – -14.72	-0.61	-1.04 – -0.18	**0.005**
Age Category [Middle Adult]	-39.47	-72.88 – -6.07	-0.49	-0.91 – -0.08	**0.021**	-39.31	-72.61 – -6.02	-0.49	-0.91 – -0.08	**0.021**
Age Category [Older Adult]	-92.94	-143.88 – -41.99	-1.16	-1.79 – -0.52	**<0.001**	-93.16	-143.93 – -42.38	-1.16	-1.79 – -0.53	**<0.001**
Gender [Man]						18.44	-8.11 – 45.00	0.23	-0.10 – 0.56	0.172
Observations	134					134				
R^2 / R^2 adjusted	0.123 / 0.103					0.136 / 0.109				

Table S C-11: Unadjusted and Adjusted linear model results for the fixed effect of age group with the outcome variable of mean daily volume of vigorous activity (min/day)

	Log$_{10}$Volume of Vigorous Activity [Unadjusted]					**Log$_{10}$ Volume of Vigorous Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	0.92	0.79 – 1.06	0.11	-0.12 – 0.34	**<0.001**	0.83	0.68 – 0.98	-0.05	-0.30 – 0.21	**<0.001**
Age Category [Child]	0.21	-0.04 – 0.45	0.35	-0.07 – 0.77	0.099	0.15	-0.09 – 0.40	0.26	-0.15 – 0.68	0.212
Age Category [Middle Adult]	-0.30	-0.54 – -0.05	-0.51	-0.92 – -0.09	**0.017**	-0.29	-0.53 – -0.06	-0.50	-0.91 – -0.10	**0.016**
Age Category [Elderly]	-0.57	-0.94 – -0.20	-0.97	-1.60 – -0.34	**0.003**	-0.57	-0.93 – -0.21	-0.97	-1.59 – -0.36	**0.002**
Gender [Man]						0.23	0.04 – 0.42	0.40	0.08 – 0.72	**0.016**
Observations	134					134				
R^2 / R^2 adjusted	0.140 / 0.121					0.179 / 0.153				

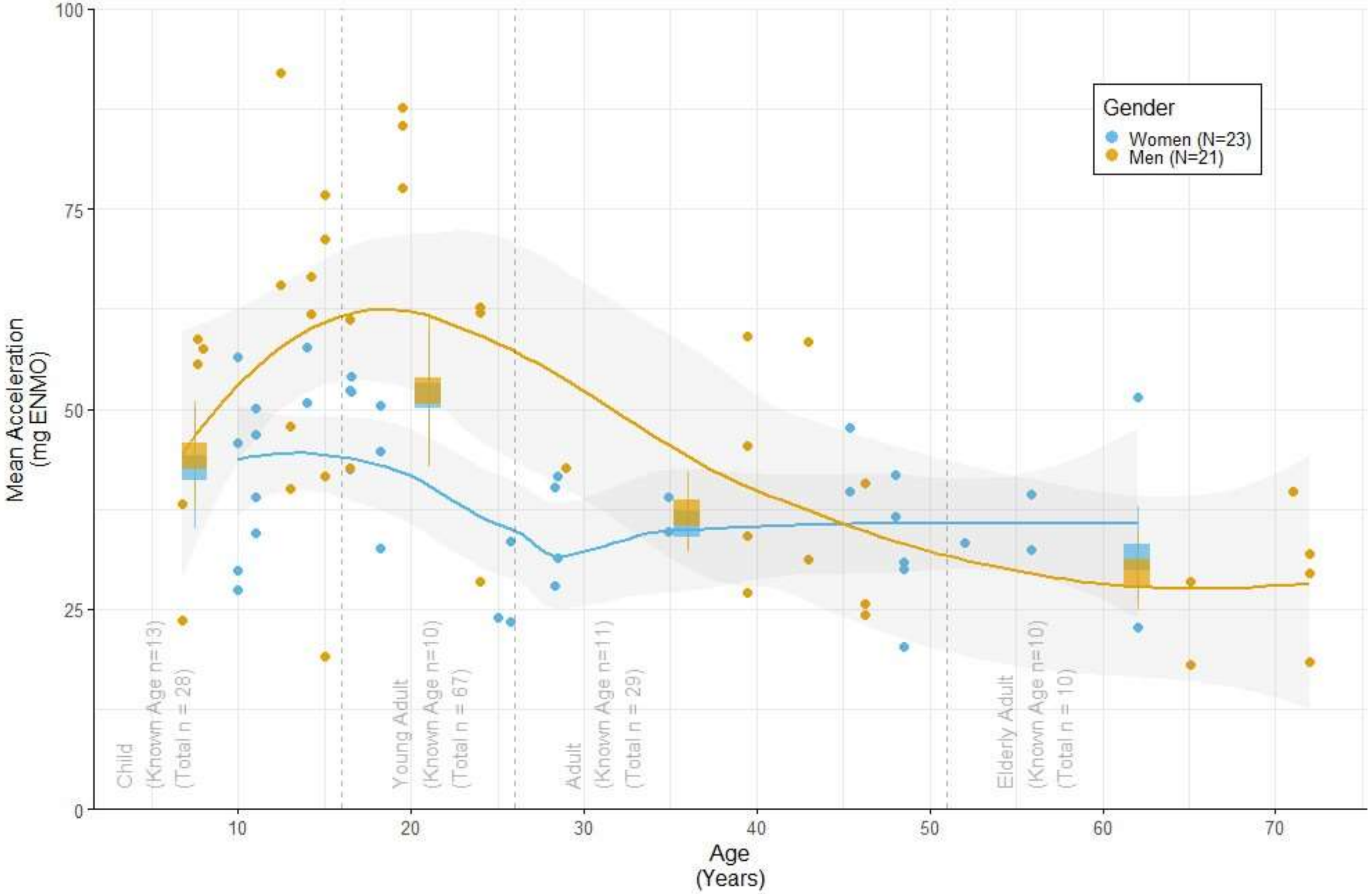


Figure C-1: Plot of mean acceleration amongst individuals with an accurately estimated age provided. Line represents LOESS fit amongst those with an accurately estimated age. Box and whiskers present the mean and confidence interval for all individuals within an age category as analysed in Chapter 5.

C.2.3 Unadjusted and Adjusted models for Maternal Status

Table S C-12: Unadjusted and Adjusted linear model results for the fixed effect of maternal status with the outcome variable of mean acceleration (mg ENMO)

	Mean Acceleration [Unadjusted]					**Mean Acceleration [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	40.86	35.24 – 46.48	-0.02	-0.42 – 0.39	**<0.001**	42.18	35.45 – 48.90	0.08	-0.41 – 0.56	**<0.001**
Maternal Status [Breast Feeding]	1.64	-6.48 – 9.75	0.12	-0.47 – 0.70	0.688	1.35	-7.09 – 9.80	0.10	-0.51 – 0.71	0.749
Maternal Status [Pregnant]	-2.19	-12.36 – 7.97	-0.16	-0.89 – 0.58	0.667	-2.37	-12.92 – 8.18	-0.17	-0.93 – 0.59	0.654
Age Category [Adult]						0.12	-9.43 – 9.67	0.01	-0.68 – 0.70	0.980
Village [Longa]						-5.65	-16.60 – 5.31	-0.41	-1.20 – 0.38	0.306
Village [Njoki]						-0.90	-12.23 – 10.43	-0.06	-0.88 – 0.75	0.874
Observations	59					59				
R^2 / R^2 adjusted	0.010 / -0.025					0.034 / -0.057				

Table S C-13: Unadjusted and Adjusted linear model results for the fixed effect of maternal status with the outcome variable of mean daily volume of sedentary activity (min/day)

	Volume of Sedentary Activity [Unadjusted]					**Volume of Sedentary Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	802.31	741.56 – 863.07	0.21	-0.19 – 0.61	**<0.001**	754.11	685.47 – 822.75	-0.10	-0.56 – 0.35	**<0.001**
Maternal Status [Breast Feeding]	-59.69	-147.46 – 28.08	-0.39	-0.97 – 0.19	0.179	-45.77	-131.97 – 40.42	-0.30	-0.87 – 0.27	0.292
Maternal Status [Pregnant]	-48.97	-158.88 – 60.94	-0.32	-1.05 – 0.40	0.376	-51.31	-159.03 – 56.42	-0.34	-1.05 – 0.37	0.344
Age Category [Adult]						46.18	-51.31 – 143.68	0.30	-0.34 – 0.95	0.346
Village [Longa]						93.25	-18.57 – 205.07	0.61	-0.12 – 1.35	0.100
Village [Njoki]						69.26	-46.40 – 184.91	0.46	-0.31 – 1.22	0.235
Observations	59					59				
R^2 / R^2 adjusted	0.035 / 0.000					0.160 / 0.081				

Table S C-14: Unadjusted and Adjusted linear model results for the fixed effect of maternal status with the outcome variable of mean daily volume of light activity (min/day)

	Volume of Light Activity [Unadjusted]					**Volume of Light Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	189.24	169.64 – 208.83	0.06	-0.34 – 0.47	**<0.001**	189.38	166.32 – 212.45	0.07	-0.41 – 0.54	**<0.001**
Maternal Status [Breast Feeding]	-12.83	-41.14 – 15.48	-0.26	-0.84 – 0.32	0.368	-15.55	-44.52 – 13.42	-0.32	-0.91 – 0.27	0.286
Maternal Status [Pregnant]	9.94	-25.51 – 45.39	0.20	-0.52 – 0.93	0.576	3.61	-32.60 – 39.81	0.07	-0.67 – 0.82	0.842
Age Category [Adult]						28.31	-4.46 – 61.08	0.58	-0.09 – 1.25	0.089
Village [Longa]						-18.60	-56.18 – 18.98	-0.38	-1.15 – 0.39	0.325
Village [Njoki]						-18.15	-57.02 – 20.72	-0.37	-1.17 – 0.42	0.353
Observations	59					59				
R^2 / R^2 adjusted	0.031 / -0.004					0.085 / -0.002				

Table S C-15: Unadjusted and Adjusted linear model results for the fixed effect of maternal status with the outcome variable of mean daily volume of moderate activity (min/day)

	Volume of Moderate Activity [Unadjusted]					**Volume of Moderate Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	163.86	128.65 – 199.06	-0.14	-0.55 – 0.26	**<0.001**	186.63	146.33 – 226.92	0.12	-0.34 – 0.58	**<0.001**
Maternal Status [Breast Feeding]	27.36	-23.50 – 78.23	0.31	-0.27 – 0.90	0.286	21.02	-29.59 – 71.62	0.24	-0.34 – 0.82	0.409
Maternal Status [Pregnant]	9.55	-54.14 – 73.25	0.11	-0.62 – 0.84	0.765	8.09	-55.15 – 71.34	0.09	-0.63 – 0.82	0.798
Age Category [Adult]						-8.30	-65.54 – 48.93	-0.10	-0.75 – 0.56	0.772
Village [Longa]						-67.53	-133.17 – -1.88	-0.77	-1.53 – -0.02	**0.044**
Village [Njoki]						-28.91	-96.81 – 38.98	-0.33	-1.11 – 0.45	0.397
Observations	59					59				
R^2 / R^2 adjusted	0.021 / -0.014					0.126 / 0.043				

Table S C-16 Unadjusted and Adjusted linear model results for the fixed effect of maternal status with the outcome variable of mean daily volume of vigorous activity (min/day)

	$\log_{10}$ Volume of Vigorous Activity [Unadjusted]					**$\log_{10}$ Volume of Vigorous Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. β*	*std. CI*	*p*	*Estimates*	*CI*	*std. β*	*std. CI*	*p*
Intercept	0.65	0.38 – 0.92	-0.11	-0.52 – 0.29	**<0.001**	0.78	0.47 – 1.09	0.08	-0.39 – 0.55	**<0.001**
Maternal Status [Breast Feeding]	0.20	-0.18 – 0.59	0.31	-0.28 – 0.89	0.297	0.18	-0.22 – 0.57	0.27	-0.33 – 0.86	0.372
Maternal Status [Pregnant]	-0.02	-0.51 – 0.46	-0.03	-0.76 – 0.70	0.928	-0.01	-0.50 – 0.48	-0.02	-0.76 – 0.72	0.962
Age Category [Adult]						-0.13	-0.57 – 0.32	-0.19	-0.86 – 0.48	0.567
Village [Longa]						-0.36	-0.87 – 0.15	-0.54	-1.30 – 0.23	0.166
Village [Njoki]						-0.10	-0.62 – 0.43	-0.15	-0.94 – 0.65	0.712
Observations	59					59				
R^2 / R^2 adjusted	0.024 / -0.011					0.090 / 0.004				

Table S C-17: Linear model results for the fixed effect of maternal status (clustered into None and Pregnant/Breastfeeding) against each outcome variable.

	Mean Acceleration	**Sedentary**	**Light**	**Moderate**	**Vigorous**
Predictors	*Estimates*	*Estimates*	*Estimates*	*Estimates*	*Estimates*
(Intercept)	40.86 *** (35.27 – 46.46)	802.31 *** (742.10 – 862.53)	189.24 *** (169.54 – 208.93)	163.86 *** (128.88 – 198.84)	12.43 *** (6.25 – 18.61)
Pregnant or Breastfeeding	0.40 (-6.97 – 7.77)	-56.22 (-135.55 – 23.10)	-5.46 (-31.40 – 20.48)	21.60 (-24.48 – 67.68)	-0.49 (-8.63 – 7.65)
Observations	59	59	59	59	59
R^2 / R^2 adjusted	0.000 / -0.017	0.034 / 0.017	0.003 / -0.014	0.015 / -0.002	0.000 / -0.017

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

C.2.4 Unadjusted and Adjusted models for Village of residence

Table S C-18: Unadjusted and Adjusted linear model results for the fixed effect of village of residence with the outcome variable of mean acceleration (mg ENMO)

	Mean Acceleration [Unadjusted]					**Mean Acceleration [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	44.64	39.72 – 49.56	-0.07	-0.35 – 0.21	**<0.001**	41.15	35.48 – 46.82	-0.27	-0.59 – 0.06	**<0.001**
Village [Longa]	7.73	-4.42 – 19.88	0.44	-0.25 – 1.13	0.208	5.29	-6.68 – 17.26	0.30	-0.38 – 0.98	0.381
Village [Njoki]	0.66	-14.50 – 15.82	0.04	-0.83 – 0.90	0.931	0.86	-13.84 – 15.55	0.05	-0.79 – 0.89	0.908
Gender [Man]						9.88	1.20 – 18.56	0.56	0.07 – 1.06	**0.026**
Observations	67					67				
R^2 / R^2 adjusted	0.025 / -0.006					0.099 / 0.056				

Table S C-19: Unadjusted and Adjusted linear model results for the fixed effect of village of residence with the outcome variable of mean daily volume of sedentary activity (min/day)

	Volume of Sedentary Activity [Unadjusted]					**Volume of Sedentary Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	727.34	685.05 – 769.62	-0.13	-0.41 – 0.14	**<0.001**	727.65	676.97 – 778.33	-0.13	-0.46 – 0.20	**<0.001**
Village [Longa]	103.34	-1.10 – 207.79	0.67	-0.01 – 1.35	0.052	103.56	-3.47 – 210.60	0.67	-0.02 – 1.37	0.058
Village [Njoki]	58.69	-71.65 – 189.03	0.38	-0.47 – 1.23	0.372	58.67	-72.75 – 190.09	0.38	-0.47 – 1.24	0.376
Gender [Man]						-0.89	-78.52 – 76.75	-0.01	-0.51 – 0.50	0.982
Observations	67					67				
R^2 / R^2 adjusted	0.063 / 0.034					0.063 / 0.019				

Table S C-20: Unadjusted and Adjusted linear model results for the fixed effect of village of residence with the outcome variable of mean daily volume of light activity (min/day)

	Volume of Light Activity [Unadjusted]					**Volume of Light Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	170.43	156.99 – 183.87	-0.06	-0.34 – 0.23	**<0.001**	177.36	161.57 – 193.14	0.09	-0.24 – 0.42	**<0.001**
Village [Longa]	12.85	-20.35 – 46.05	0.27	-0.43 – 0.97	0.442	17.70	-15.64 – 51.03	0.37	-0.33 – 1.07	0.293
Village [Njoki]	8.55	-32.88 – 49.98	0.18	-0.69 – 1.05	0.681	8.17	-32.76 – 49.09	0.17	-0.69 – 1.03	0.691
Gender [Man]						-19.62	-43.80 – 4.56	-0.41	-0.92 – 0.10	0.110
Observations	67					67				
R^2 / R^2 adjusted	0.011 / -0.020					0.050 / 0.005				

Table S C-21: Unadjusted and Adjusted linear model results for the fixed effect of village of residence with the outcome variable of mean daily volume of moderate activity (min/day)

	Volume of Moderate Activity [Unadjusted]					**Volume of Moderate Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	204.20	178.88 – 229.51	0.08	-0.20 – 0.36	**<0.001**	193.56	163.63 – 223.49	-0.04	-0.37 – 0.30	**<0.001**
Village [Longa]	-34.41	-96.93 – 28.12	-0.38	-1.08 – 0.31	0.276	-41.85	-105.07 – 21.36	-0.46	-1.17 – 0.24	0.191
Village [Njoki]	-24.80	-102.82 – 53.23	-0.28	-1.14 – 0.59	0.528	-24.20	-101.82 – 53.41	-0.27	-1.13 – 0.59	0.535
Gender [Man]						30.14	-15.71 – 75.99	0.33	-0.17 – 0.84	0.194
Observations	67					67				
R^2 / R^2 adjusted	0.022 / -0.008					0.048 / 0.003				

Table S C-22: Unadjusted and Adjusted linear model results for the fixed effect of village of residence with the outcome variable of mean daily volume of vigorous activity (min/day)

	Log_{10} Volume of Vigorous Activity [Unadjusted]					**Log_{10} Volume of Vigorous Activity [Adjusted]**				
Predictors	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*	*Estimates*	*CI*	*std. ß*	*std. CI*	*p*
Intercept	0.93	0.75 – 1.12	0.01	-0.27 – 0.30	**<0.001**	0.83	0.61 – 1.04	-0.15	-0.48 – 0.18	**<0.001**
Village [Longa]	0.05	-0.40 – 0.50	0.08	-0.62 – 0.78	0.829	-0.02	-0.48 – 0.43	-0.04	-0.74 – 0.66	0.916
Village [Njoki]	-0.17	-0.74 – 0.40	-0.26	-1.14 – 0.61	0.550	-0.16	-0.72 – 0.39	-0.25	-1.11 – 0.60	0.557
Gender [Man]						0.30	-0.03 – 0.63	0.46	-0.05 – 0.96	0.076
Observations	67					67				
R^2 / R^2 adjusted	0.007 / -0.024					0.056 / 0.011				

Table S C-23: Linear model results for the fixed effect of village (clustered into town (Sembola) and Forest (Longa and Njoki) and each outcome variable.

	Mean Acceleration	**Sedentary**	**Light**	**Moderate**	**Vigorous**
Predictors	*Estimates*	*Estimates*	*Estimates*	*Estimates*	*Estimates*
(Intercept)	44.64 *** (39.74 – 49.54)	727.34 *** (685.28 – 769.39)	170.43 *** (157.10 – 183.77)	204.20 *** (179.08 – 229.32)	16.97 *** (12.06 – 21.88)
Forest Campsites	5.08 (-4.95 – 15.11)	86.60 * (0.54 – 172.66)	11.24 (-16.05 – 38.53)	-30.80 (-82.21 – 20.60)	-0.65 (-10.70 – 9.40)
Observations	67	67	67	67	67
R^2 / R^2 adjusted	0.015 / 0.000	0.058 / 0.044	0.010 / -0.005	0.022 / 0.007	0.000 / -0.015

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

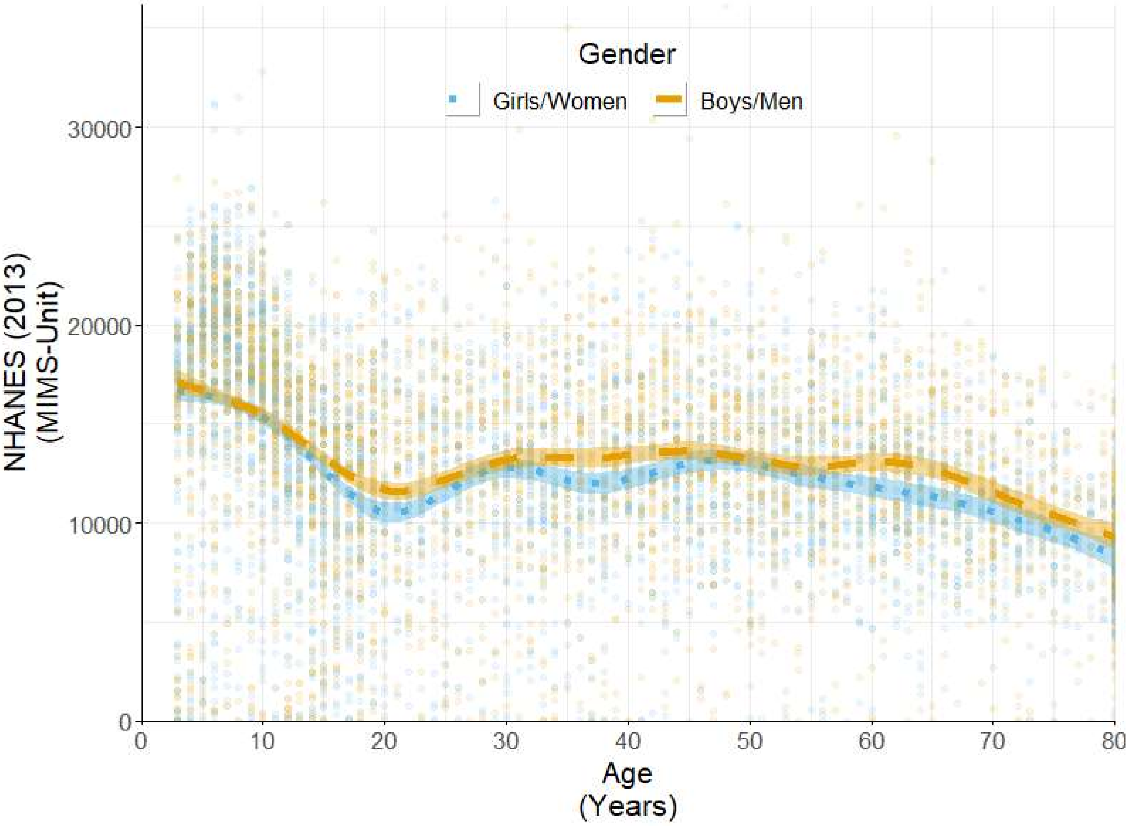


Figure S C-2: Mean intensity of activity with the 2013 NHANES data collection. Activity is presented in Monitor Independent Motion Sensing (MIMS) Units. Plot includes all individuals aged between 5 and 80. Individuals older than 80 were recoded to 80 by the data holders to preserve the anonymity of this subset.

Appendix D Appendix to Chapter 6: Distributions of physical activity in BaYaka Children of Congo-Brazzaville

Table S D-1: NHANES summary data. Data used in the present chapter comes from the 2013-14 data collection of the National Health and Nutrition Exmaination Survey. *MIMS: Monitor Independent Motion Sensing. A measure of total acceleration experienced by the device, averaged between days. More information on the NHANES dataset and access can be found at " https://wwwn.cdc.gov/nchs/nhanes/Default.aspx "

	Overall	**Boys**	**Girls**
n	2391	1200	1191
Age (mean (SD))	11.68 (3.99)	11.60 (4.00)	11.76 (3.99)
Ethnicity			
Mexican American	556 (23.3)	272 (22.7)	284 (23.8)
Other Hispanic	241 (10.1)	120 (10.0)	121 (10.2)
Non-Hispanic White	610 (25.5)	332 (27.7)	278 (23.3)
Non-Hispanic Black	600 (25.1)	296 (24.7)	304 (25.5)
Other	384 (16.1)	180 (15.0)	204 (17.1)
Mean Acceleration (MIMS Unit)* **(mean (SD))**	14672.97 (5909.61)	14533.87^{c} (6092.66)	14813.12^{c} (5718.38)

Note: *MIMS: Monitor Independent Motion Sensing. A measure of total acceleration experienced by the device, averaged between days. More information on the NHANES dataset and access can be found at " https://wwwn.cdc.gov/nchs/nhanes/Default.aspx ". c = In linear models adjusted for age, girls and boys recorded similar MIMS-Units per day (β = -209, SE = 248.52, p = 0.40).

Table S D-2: Millennium Cohort Summary Data. Data presented comes from the 6th sweep of the Millennium Cohort when participants were aged 14. Further information on the study can be found at "

	Overall	Boys	Girls
n	4533	2182	2351
Age (Years)	14.23 (0.50)	14.23 (0.56)	14.23 (0.44)
Height (cm)	163.86 (8.07)	166.68 (8.70)	161.23 (6.41)
Weight (kg)	57.55 (12.80)	57.90 (13.40)	57.22 (12.18)
BMI	21.34 (4.07)	20.70 (3.84)	21.95 (4.19)
Body Fat (%)	21.91 (9.13)	16.46 (7.89)	27.09 (6.97)
Season (%)			
Autumn	961 (22.0)	472 (22.6)	489 (21.5)
Spring	1410 (32.3)	671 (32.1)	739 (32.5)
Summer	1385 (31.7)	651 (31.1)	734 (32.3)
Winter	608 (13.9)	297 (14.2)	311 (13.7)
Ethnicity (%)			
White	3714 (83.1)	1785 (83.0)	1929 (83.1)
Black or Black British	116 (2.6)	53 (2.5)	63 (2.7)
Indian	112 (2.5)	60 (2.8)	52 (2.2)
Pakistani or Bangladeshi	251 (5.6)	109 (5.1)	142 (6.1)
Mixed	181 (4.0)	97 (4.5)	84 (3.6)
Other	97 (2.2)	46 (2.1)	51 (2.2)
Mean Acceleration (Mg ENMO)	34.01 (13.26)	36.81 (15.31)[a]	31.42 (10.36)[a]
MVPA (mean (SD))	128.58 (54.86)	134.10[b] (59.77)	123.46[b] (49.34)

Note: Further information on the study can be found at " https://cls.ucl.ac.uk/cls-studies/millennium-cohort-study/ ". Data is accessible via the UK Data Service. a = in linear models adjusted for age and BMI, compared to boys the mean acceleration amongst girls was lower (β = -5.10, SE = 0.40, p <0.001). b = in linear models adjusted for age and BMI, compared to boys the volume of MVPA amongst girls was lower (β= -10.05, SE = 1.67, p <0.001).

D.1 Comparisons to data collected in 2018.

The volumes of activity in the present study are similar to those observed amongst BaYaka children in 2018 (see Chapter 5). The mean acceleration was marginally higher for both genders in 2018, which is likely caused by the approximate 30-minute increase in the volume of MVPA undertaken in the earlier field season. However, there is sizable variability within in each sample year precluding any confidence in stating a meaningful difference between the years. Possibly driving this is that the season of recording was different, which may have put different requirements on activity amongst children. Volumes of light activity were broadly similar between the two years, at approximately 3hrs a day.

Table S D-3: Comparison of physical activity data collected in 2018 and 2022. Data includes aggregated data for all individuals.

	Overall	2018		2022	
		Boys	**Girls**	**Boys**	**Girls**
n	35	7	5	12	11
Age	11.53 (3.72)	12.31 (3.47)	12.91 (3.32)	10.75 (4.63)	11.27 (3.10)
Mean Acceleration (mg ENMO)	48.80 (11.43)	59.90 (14.82)	50.07 (3.50)	47.28 (7.91)	42.80 (10.46)
Sedentary (Min/Day)	1038.24 (78.28)	997.77 (85.16)	1008.72 (33.27)	1049.86 (67.86)	1064.74 (91.97)
Light (Min/Day)	192.24 (30.44)	202.19 (26.62)	225.26 (14.11)	180.93 (21.90)	183.24 (35.51)
MVPA (Min/Day)	213.08 (62.33)	262.83 (67.19)	206.02 (20.51)	205.86 (52.89)	192.53 (70.51)
Of Which: Moderate (Min/Day)	192.64 (55.81)	230.57 (59.34)	186.26 (20.76)	187.96 (52.13)	176.52 (63.04)
Of Which: Vigorous (Min/Day)	18.50 (11.66)	32.26 (13.78)	19.76 (2.94)	16.87 (10.17)	10.97 (5.66)

D.2 Distribution across the day

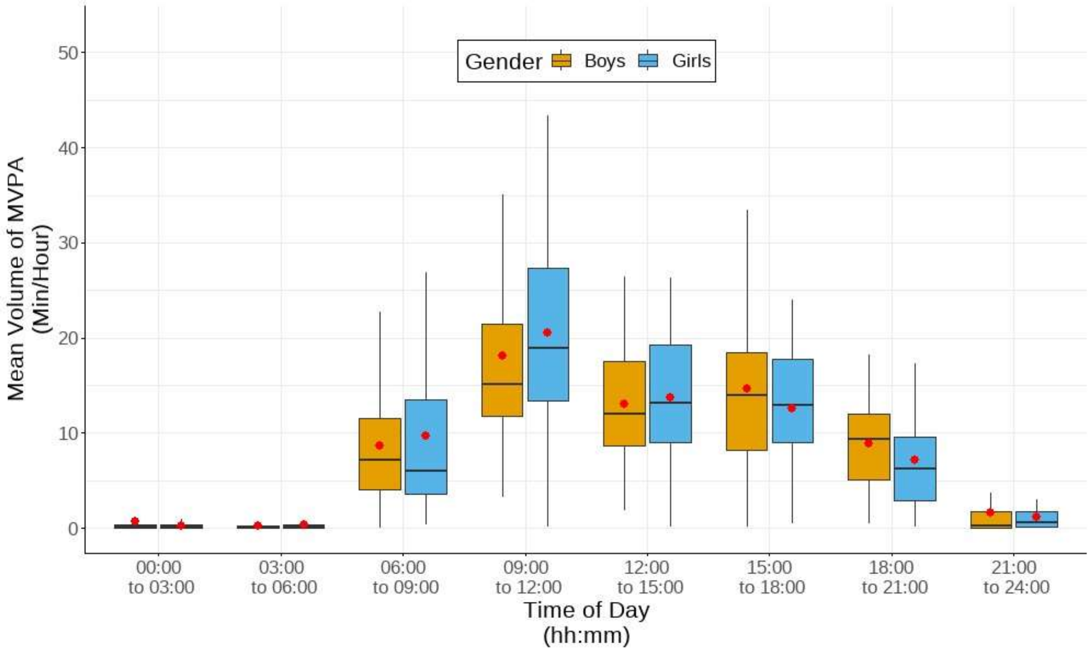


Figure S D-1: Boxplot of hourly volume of MVPA across the day, clustered into chunks of 3 hours, grouped by gender.

Table S D-4: Linear mixed effect model coefficients for mean hourly volume of MVPA at each three-hour interval of time. The effect of age and gender are included as fixed effects with the day of recording nested within each individual as a random effect. All complete days were included for all individuals. Reference is a Boy aged 0. Values are estimate and 95% confidence interval. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

	MVPA
Predictors	*Estimates*
(Intercept)	-4.76 *** (-7.31 – -2.21)
03:00 – 06:00	-0.21 (-1.55 – 1.13)
06:00 – 09:00	8.63 *** (7.29 – 9.97)
09:00 – 12:00	18.67 *** (17.33 – 20.01)
12:00 – 15:00	12.86 *** (11.52 – 14.19)
15:00 – 18:00	13.25 *** (11.92 – 14.59)
18:00 - 21:00	7.66 *** (6.32 – 8.99)
21:00 – 24:00	0.93 (-0.41 – 2.26)
Age	0.50 *** (0.30 – 0.71)
Gender [Girl]	-0.67 (-2.26 – 0.91)
Random Effects	
σ^2	26.68
τ_{00} (weekday:ID)	1.98
τ_{00} (ID)	2.53
ICC	0.14
N $_{\text{weekday}}$	5
N ID	23
Observations	920
Marginal R^2 / Conditional R^2	0.601 / 0.659

D.3 Variation between days

Table S D-5: Linear model estimates for standardised (z-scored) mean activity, adjusting for study, age and gender. Reference is a BaYaka boy. Values are estimate and 95% confidence interval * p<0.05 ** p<0.01 *** p<0.001.

	Standardised Mean Activity (Z-Scored)
Predictors	***Estimates***
(Intercept)	-0.52 * (-1.16 – -0.13)
Gender [Girl]	0.05 (-0.00 – 0.11)
Age	0.05 (-0.0– 0.11)
Population [NHANES]	1.19 *** (0.54 – 1.84)
Age × Population [NHANES]	-0.11 *** (-0.17 – -0.06)
Random Effects	
σ^2	0.33
τ_{00}	0.56 id
ICC	0.63
N	2772 id
Observations	14451
R^2 / R^2 adjusted	0.082 / 0.658

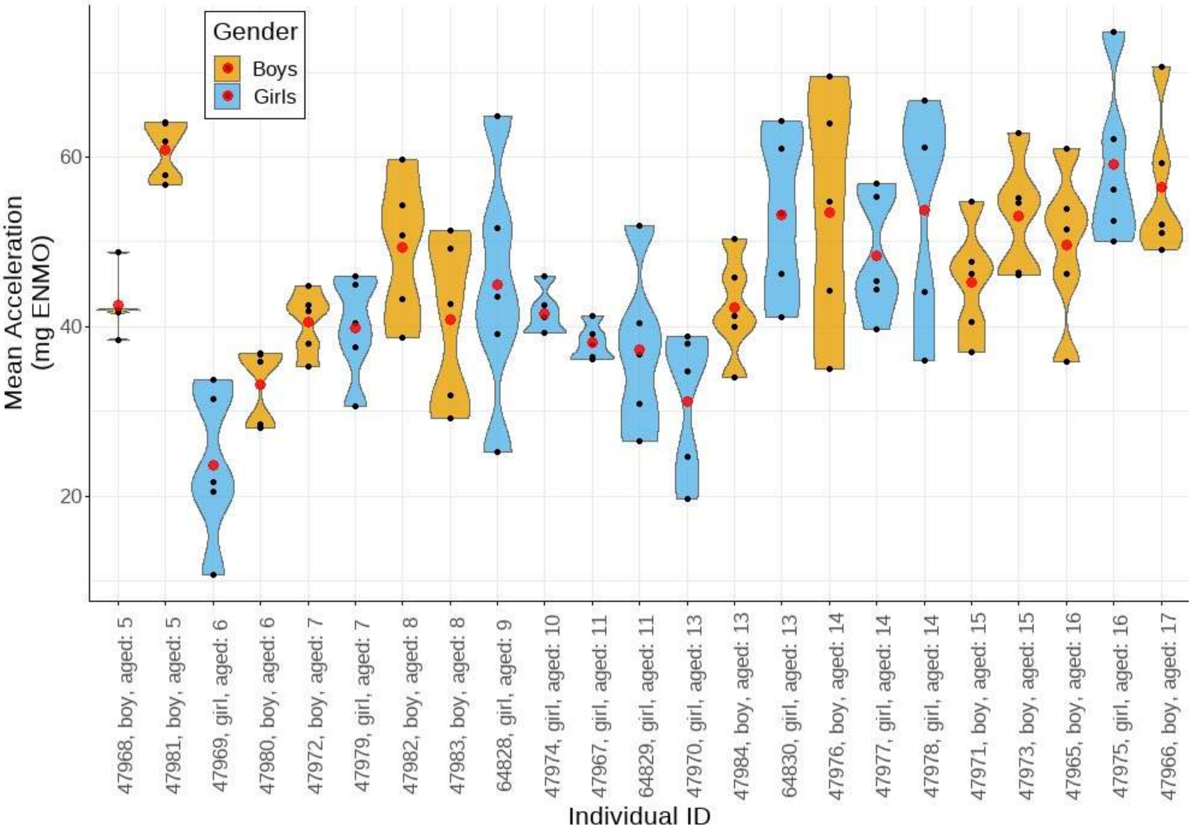


Figure S D-2: Violin plot of individual variation in mean acceleration across 5 days of recording in the 2022 field trip. Red point represents each individuals mean acceleration across all complete days of recording; each grey point represents the mean acceleration on a given day of recording. Individuals are arranged in increasing age, with colours set by gender.

Table S D-6: Full model mixed effect model of standardised mean accelerations in three hour windows across the day in the BaYaka and NHANES sample. The effect of age and gender are included as fixed effects with the day of recording nested within each individual as a random effect. All complete days were included for all individuals. Reference is the standardised acceleration of a BaYaka child between 3am and 6am. Values are estimate and 95% confidence interval. *** p < 0.001; ** p < 0.01; * p < 0.05.

	Mean Acceleration (Z-Score)
Predictors	*Estimates*
(Intercept)	-0.51 *** (-0.70 – -0.32)
0-3am	0.03 (-0.14 – 0.20)
7-9am	1.11 *** (0.94 – 1.28)
10-12am	2.22 *** (2.05 – 2.38)
13-15pm	1.74 *** (1.58 – 1.91)
16-18pm	1.75 *** (1.58 – 1.92)
19-21pm	1.15 *** (0.98 – 1.31)
22-24pm	0.18 * (0.01 – 0.35)
Girl	-0.02 (-0.04 – 0.01)
Age	-0.05 *** (-0.05 – -0.04)
NHANES: 0-3am	0.02 (-0.14 – 0.19)
NHANES: 3-6am	0.11 (-0.07 – 0.30)
NHANES: 7-9am	**-0.35** *** **(-0.52 – -0.18)**
NHANES: 10-12am	**-0.83** *** **(-1.00 – -0.66)**
NHANES: 13-15pm	-0.16 (-0.33 – 0.01)

NHANES: 16-18pm	-0.12 (-0.29 – 0.05)
NHANES: 19-21pm	**0.37** *** **(0.20 – 0.54)**
NHANES: 22-24pm	**0.44** *** **(0.27 – 0.61)**
Random Effects	
σ^2	0.42
$\tau_{00\ \mathrm{weekday:id}}$	0.03
$\tau_{00\ \mathrm{id}}$	0.11
ICC	0.25
N_{weekday}	12
N_{id}	2483
Observations	135925
Marginal R^2 / Conditional R^2	0.438 / 0.579

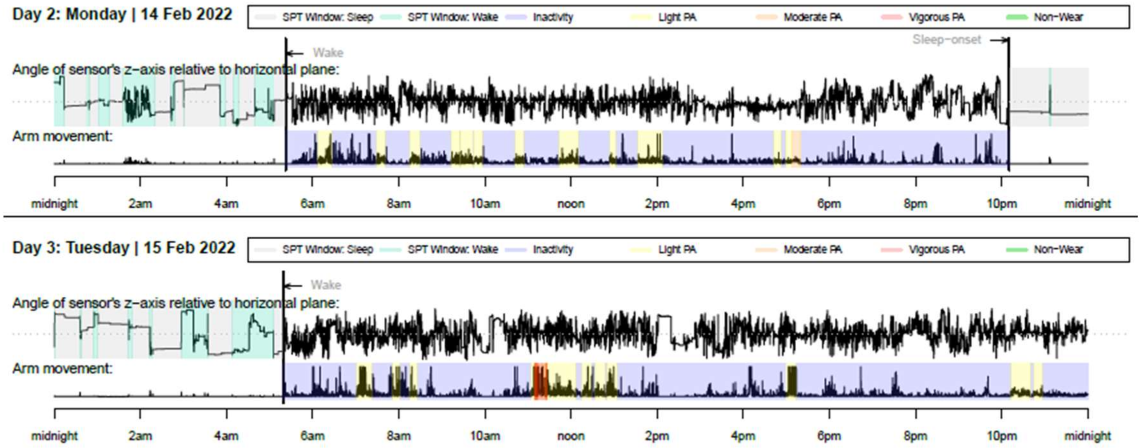


Figure S D-3: Sample output from GGIR for one child's data from 2022. The image contains a 2-day snippet of activity. Periods of sleep are marked in grey, with the border between wakeful activity and the sleep period marked by a solid vertical line. The coloured scale of purple through the red at the bottom of each day's trace shows the intensity of the activity engaged in.