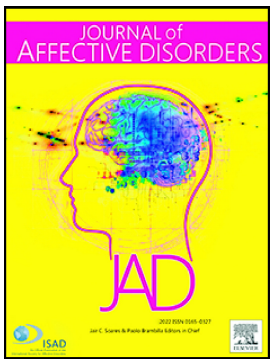

Associations between the composition of daily time spent in physical activity, sedentary behaviour and sleep and risk of depression: Compositional data analyses of the 1970 British cohort study

J.M. Blodgett, J.J. Mitchell, E. Stamatakis, S. Chastin, M. Hamer

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Associations between the composition of daily time spent in physical activity, sedentary behaviour and sleep and risk of depression: compositional data analyses of the 1970 British Cohort study

Blodgett JM[a], Mitchell JJ[a], Stamatakis E[b], Chastin S[c,d], Hamer M[a]

[a] Institute of Sport Exercise & Health, Division of Surgery & Interventional Science, University College London, 170 Tottenham Court Road, W1T 7HA, London, UK
[b] Charles Perkins Centre, School of Health Sciences, Faculty of Medicine and Health, The University of Sydney, NSW, Australia
[c] School of Health and Life Sciences, Glasgow Caledonian University, Glasgow, Scotland, UK
[d] Department of Movement and Sports Sciences, Ghent University, Ghent, Belgium

*** Corresponding Author:**
Joanna M Blodgett
Institute of Sport Exercise & Health
Division of Surgery & Interventional Science
University College London
170 Tottenham Court Road
W1T 7HA
London, UK
Email: joanna.blodgett@ucl.ac.uk
Number: +44 7470504084

Abstract

Background: The benefits of moderate to vigorous physical activity(MVPA) in lowering depression risk are well established, but there is mixed evidence on sleep, sedentary behaviour(SB), and light-intensity physical activity(LIPA). These behaviours are often considered in isolation, neglecting their behavioural and biological interdependences. We investigated how time spent in one behaviour relative to others was associated with depression risk.
Methods: We included 4738 individuals from the 1970 British Cohort study (age 46 wave). Depression status was ascertained using self-reported doctor visits and prescribed anti-depressant use. MVPA, LIPA, SB and sleep were ascertained using thigh-worn accelerometers worn consecutively for 7 days. Compositional logistic regression was used to examine associations between different compositions of time spent in movement behaviours and depression.
Results: More time spent in MVPA, relative to SB, sleep or LIPA, was associated with a lower risk of depression. When modelling reallocation of time (e.g. replacing time in one behaviour with another), replacing sleep, SB or LIPA with MVPA time was strongly associated with lower depression risk. Reallocating time between SB, sleep or LIPA had minimal to no effect.
Limitations: Data was cross-sectional, therefore causality cannot be inferred. Accelerometers do not capture SB context (e.g. TV watching, reading) nor separate biological sleep from time spent in bed.
Conclusions: Displacing any behaviour with MVPA was associated with a lower risk of depression. This study provides promising support that increasing MVPA, even in small doses, can have a positive impact on prevention, mitigation and treatment of depression.

Key words: depression, physical activity, sleep, sedentary behaviour, compositional data analysis, epidemiology

Background

Mental health problems are the primary driver of disability worldwide[1, 2], directly impacting more than 10% of the global population[3]. Changes in lifestyle behaviours offer low cost and non-invasive alternative solutions to reduce the onset and severity of mental health disorders[4]. There is strong evidence that moderate to vigorous physical activity (MVPA) has a positive impact on reducing risk of incident depression and symptom severity[2]. However, the role of sedentary behaviour (SB), lower intensity physical activity (LIPA) and sleep are not well understood[5, 6], with most evidence relying on self-reported measurements, which are subject to social desirability and recall bias[7].

A key challenge in physical activity (PA) epidemiology is that these behaviours are studied in isolation, with little consideration of how they impact one another across the 24-hour day. Traditional analytical approaches consider how a single unit increase (e.g. per minute/hour) in a behaviour impacts depression risk, but fail to recognise i) the finite nature of the 24-hour day and ii) that any increase in one behaviour displaces time spent in another. Compositional data analysis is a novel technique that considers all behaviours in relation to one another[8]. Using a compositional data analysis approach, we investigated: i) how time spent in one behaviour relative to others (e.g. MVPA, LIPA, sleep, SB) across the 24-hour day was associated with depression risk and ii) how the risk of depression changes, by modelling the redistribution of time spent in each of these behaviours.

METHODS

Study sample

The 1970 British Cohort Study is a longitudinal study of 16571 individuals born in England, Scotland and Wales during a single week in 1970. Study participants have been followed up across life, participating in up to 10 assessments. The age 46 sweep took place between 2016 and 2018 (n=8581), and consisted of a 50-minute interview and questionnaire, a 50-minute biomedical assessment and fitting of a thigh-worn accelerometer on those who consented (n=6562 of 7439 invited). Participants provided informed consent and ethical approval was given from the NRES Committee South East Coast–Brighton and Sussex (Ref:15/LO/1446).

Thigh-worn accelerometer

The 24-hour wear protocol of the activPAL3 micro device (PAL Technologies Ltd., Glasgow, United Kingdom), based on the SeniorUSP protocol[9], has been previously described[10]. Briefly, nurses waterproofed and fitted the device on the midline anterior aspect of the upper thigh. Participants were requested to wear the device continuously for 7 days, including sleeping and bathing, and to not re-attach the device. Of the 6562 individuals who consented to wear an accelerometer, nurses could not initiate 102(1.6%), 591(9.0%) were not returned and data could not be downloaded for 858(13.0%) leaving 5011 individuals with valid data.

Information on thigh inclination and acceleration was used to derive body posture across the 24-hour day[10]. An algorithm separated out bouts of valid

waking wear data from non-wear or sleep[11]. *Sleep* was classified as the longest reclining bout between noon and noon each day (min ≥2 hours) or any long bouts lasting ≥5 hours. *SB* was defined as non-sleep time spent sitting or lying. *MVPA* was defined using the established step cadence threshold of ≥100[10], while all other PA was classified as *LIPA*.

Depression

Nurses recorded medication and were coded at the sub-chapter level using the British National Formulary(BNF) edition 69. A diagnosis of depression was assigned if participants reported taking prescribed anti-depressants (BNF4:0403) and had seen a doctor or specialist since the age 42 wave due to feeling low, depressed or sad. Of 5011 with valid accelerometer data, depression status could not be ascertained for five(0.1%) individuals.

Covariates

All covariates were assessed at age 46 and included *sex*, *academic qualification*s (none, up to A levels/diploma, degree/higher), occupational type (not working, sitting, standing, physical, heavy manual), *marital status* (never married, married/civil partner, divorced/widowed/separated), *smoking status* (never, ex-, occasional, daily), *drinking status* (non-drinker, non-problem drinker, problem drinker; derived using the Alcohol Use Disorders Identification Test), *disability* (none, some, severe using the European Union Statistics on Income and Living Conditions classification), *immediate word recall* (max: 0-10 words), and *body mass index* (BMI; ascertained using nurse-measured height and weight). Of 5006 with valid accelerometer and depression data, 4738(96.4%) had complete covariate data.

Statistical analysis

Characteristics of the sample, including covariates, time spent in each behaviour and log-ratio differences, were compared by depression status. A composition is defined as the proportion of time spent in each of the four movement behaviours (sleep, SB, MVPA, LIPA)[8]. We followed the isometric log-ratio (*ilr*) transformation approach[8] to conduct compositional logistic regression and determine associations between movement compositions and depression risk (**Supplementary File 1** for further detail). The relative time spent in each behaviour is expressed with three coordinates included in a single regression model: i) SB compared to sleep, LIPA and MVPA; ii) sleep compared to LIPA and MVPA; iii) LIPA compared to MVPA). After assessment of sex interactions, a sex-adjusted logistic model and a covariate-adjusted model are presented.

Odds ratios were expressed as the change in depression risk per 1 unit *ilr* increase. To estimate how displacing one behaviour by another might impact depression risk[12], we used the sex-adjusted model to estimate depression risk associated with different compositions of the behaviours. Time spent in one behaviour was replaced by time spent in another behaviour, whilst keeping the other two behaviours constant (e.g. 10 minutes of MVPA replaced with 10 minutes of SB, no change in LIPA or sleep time). All analyses were performed in RStudio using the *Compositions*, *robCompositions* and *zCompositions* packages. Code was adapted from McGregor et al., 2020[12].

Results

Individuals with depression were more likely to be female, working in a sitting job, have lower academic qualifications, be divorced/widowed/separated, be daily smokers and non-drinkers, have a disability, higher verbal memory and have higher BMI than those without depression (**Supplemental Table 1**). Those with depression spent more time in SB (composition mean: 9.72hrs vs 9.29hrs) and sleep (8.58hrs vs 8.29hrs) and less time in LIPA (5.12hrs vs 5.64hrs) and MVPA (0.59hrs vs 0.78hrs). Expression of log ratio differences in compositional means shows how daily behaviours differ by depression status. Relative to the sample mean, those with depression spent 4.1% more time in SB, 3.2% more in sleep, 9.0% less time in LIPA and 26.3% less time in MVPA (**Figure 1**).

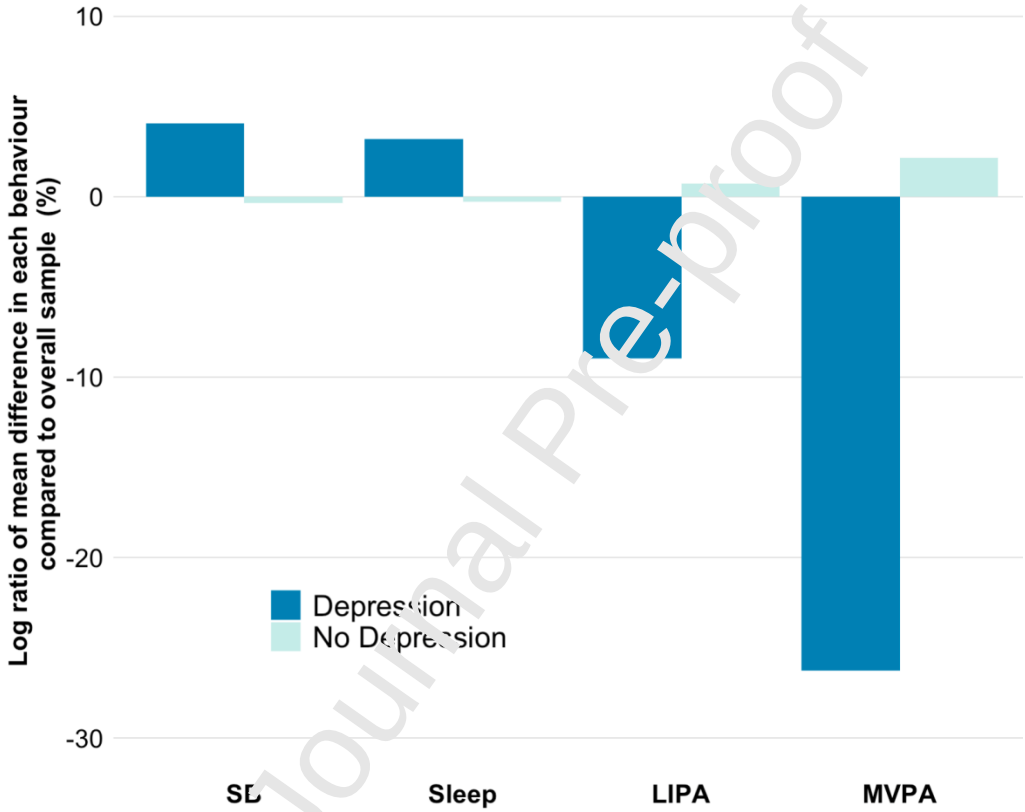

Figure 1. *Relative difference in time (expressed as a log-ratio difference) spent in each behaviour by depression status in comparison to the overall sample mean composition.*

In sex-adjusted models, more daily time spent in LIPA and MVPA, relative to the other behaviours, was associated with a lower risk of depression, whereas more time spent sedentary or sleeping was associated with a higher risk (**Supplemental Table 2**). In adjusted models, associations were retained but somewhat attenuated for sleep and MVPA, strengthened for LIPA and fully explained for SB.

Modelling reallocation of time between behaviours indicated that replacing any behaviour with MVPA, while holding the others constant, was associated with markedly lower depression risk (**Figure 2**). There was a similar association regardless of what behaviour was exchanged with MVPA (**Figure 2A)**. Replacing sleep or SB with LIPA was associated with a slightly lower depression risk (**Figure 2B**). The opposite pattern emerged for sleep time (**Figure 2C**);

increasing sleep at the expense of MVPA, LIPA or SB was associated with higher depression risk. Finally, depression risk was lower if SB was replaced with LIPA or MVPA but risk was higher when replaced by sleep (**Figure 2D**).

The effects of displacing sleep, SB and LIPA time with one another were small, while reallocating MVPA time had a substantial impact on depression risk. For example, the model suggested that reallocation of 18, 21 or 24 daily minutes of sleep, SB or LIPA, respectively, into MVPA was associated with a 20% lower depression risk. Conversely, a 20% lower depression risk was only seen if 4 hours of sleep or 1.5 hours of SB were replaced by LIPA (**Figure 2A-B**).

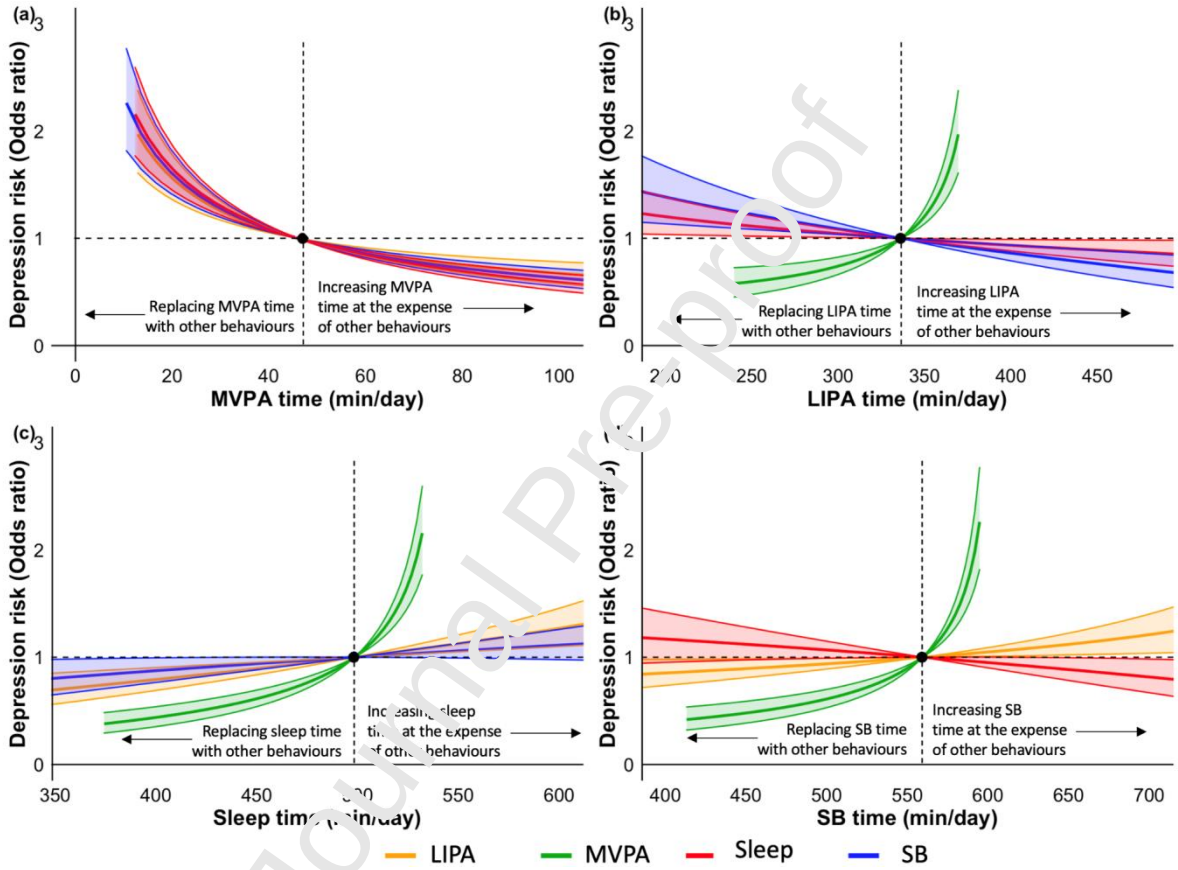

Figure 2. *Association between different compositions (modelling the reallocation of one behaviour into another while holding the other two constant) and depression risk using the sex-adjusted model for* ***A.*** *sedentary behaviour.* ***B.*** *Sleep.* ***C.*** *Light-intensity physical activity and* ***D.*** *Moderate-vigorous physical activity. Note that some lines do not cover the entire x-axis as it is not possible to have a negative allocation of time to a component. Reference (dashed line) is the sample compositional mean: 46 minutes(0.77hrs) of MVPA, 336 minutes(5.6hrs) of LIPA, 498 minutes(8.3hrs) of sleep and 559 minutes(9.32hrs) of SB.*

Discussion

Using a compositional data analysis approach[8] and a 24-hour measurement protocol, we found that more time spent in active behaviours, relative to sleep or SB, was associated with decreased risk of depression. Associations were strongest for MVPA, highlighting the importance of PA intensity, with a weak association between less LIPA time and higher depression risk. This study adds to the growing evidence on how movement behaviour across the 24-hour day

may contribute to better mental health. In contrast to the 'Move more, Sit Less' public health message suggesting benefits are yielded from any reduction in SB or increase in activity[13-15], our results indicate that MVPA may be crucial for modifying risk of depression.

Study results are consistent with previous evidence showing the importance of MVPA, while providing further clarity on SB and LIPA. Evidence from non-compositional analytical approaches suggests that lower SB and higher LIPA are associated with lower depression risk[5, 16]. However, these approaches consider individual behaviours in isolation and do not recognise the impact that an increase in one activity has on others. Our results suggest that the benefits of increasing time spent in LIPA (by decreasing non-active behaviours) and decreasing time spent in SB (by increasing active behaviours) are marginal and would likely require very large doses of change to have a minimal effect.

Evidence from compositional data approaches shows that increasing MVPA remains the most beneficial reallocation of time across the day for depression outcomes[14, 17, 18]. However, there are some inconsistent findings of other behaviours. For example, del Pozo Cruz et al.[14] reported that reallocating SB time with MVPA or sleep, and not LIPA, was associated with lower depression risk in a cross-sectional study of American adults. Kitano et al.[15] suggested that reallocation of time from SB or LIPA to sleep during weekdays in a cross-sectional study of working Japanese adults was the most beneficial change in behaviour.
Given cultural differences in sleep duration, efficiency and perceived need in Japan[19], country level differences may explain why the benefits of sleep and MVPA differ between studies. Notably, Kitano et al. [15] reported an average sleep duration of 5.7hrs and 7.1hrs on weekday and weekend nights, respectively. Therefore, the benefits of increasing sleep in a sleep-deprived sample may be more important than increasing sleep in a sample with adequate sleep (mean sleep duration of study sample: 8.3hrs). Other studies presented comparable results to those shown here, with no association of LIPA, SB or sleep with depression risk after considering the relative time spent in MVPA and other behaviours[18, 20].

The key strengths of this study are the compositional data analysis approach, the 24-hour objective ascertainment of behaviours, the age homogeneity of the sample and in-home nurse assessments to ascertain depression status. Other compositional data analysis studies in this area have used waking protocols or wrist or hip worn accelerometers[14, 15, 17, 18, 20], which are less accurate for capturing sitting or lying behaviours. Many relied on self-reported scales that overestimate depression risk when compared to clinician-diagnosed or prescribed antidepressant use[14, 15, 17, 18, 20]. The main limitation of this study is the cross-sectional design, as reverse causality cannot be ruled out. Even so, an alternative interpretation of these cross-sectional analyses is meaningful as it highlights the detrimentally low levels of MVPA in this clinically depressed sample (-23% compared to full sample). Additionally, SB context could not be captured; further research must investigate how specific behaviours (e.g. TV watching, reading, computer use) are associated with depression risk using compositional approaches[5]. Sleep time may have been overestimated as the device did not capture biological sleep. Finally, we used a modelling approach in a sex-adjusted model with observational data to reallocate time between

behaviours which cannot directly support causal inference. Reallocation of behaviours may differ by individual characteristics (e.g. country, sex, socioeconomic position, current health behaviours) and therefore interpretation must be done with caution.

Interventions aiming to increase LIPA or reduce SB are common; these non-intrusive 'nudge' changes are hypothesised to combat motivational, emotional, or physical obstacles that impede MVPA in individuals with depression[21]. However, our results emphasise that MVPA is the single most important behaviour in the 24-hour day for depression risk.

Conclusions

Greater MVPA, relative to time spent in SB, sleep or LIPA, is associated with a lower risk of depression. Reallocation of any behaviour to MVPA can lower risk of depression, even in small doses. This highlights the necessity of higher intensity PA, which should be incorporated in preventative and treatment policies for depression outcomes. Reallocating time spent in sleep or SB into LIPA had little to no effect on depression, therefore our findings caution against the acceptance of LIPA as a more feasible behavioural change that MVPA. Reallocation of sleep to MVPA was beneficial for reducing risk of depression, contrasting current recommendations that sleep should be prioritised over MVPA[15]. Future research using similar approaches must assess longitudinal associations to ascertain how reallocation of health behaviours can prevent onset of incident depression.

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Availability of data and materials: The datasets supporting this article are available in the UK Data Service repository [1970 British Cohort Study: https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=200001].

Author contributions: JMB and MH conceived the idea. JJM and SC advised on the statistical analysis. JMB performed all analyses and wrote the initial draft. All authors contributed to the final manuscript.

Conflict of interests: The authors declare that they have no competing interests.

Highlights:

- We investigated how time spent active, sedentary and asleep influenced depression risk.
- Compositional data analysis suggested that replacing any behaviour with moderate-vigorous activity could lower depression risk.
- Increasing moderate-vigorous activity by up to 25 minutes/day was associated with a 20% lower risk of depression.
- An equivalent reduction of 20% would require 4 hours of sleep or 1.5 hours of sedentary behaviour to be replaced by light-intensity activity.
- Moderate-vigorous activity may play a key role in preventing, mitigating or treating depression.