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Behavioral contributors to children's physical activity: investigating activity compensation and activity synergy in British 8-13 year olds

Anna Goodman[1], Roger L. Mackett[2] & James Paskins[2]

[1]Department of Epidemiology and Population Health, London School of Hygiene and Tropical Medicine, London UK;

[2] Centre for Transport Studies, University College London, London UK

Correspondence to: Anna Goodman, Department of Epidemiology and Population Health, London School of Hygiene and Tropical Medicine (LSHTM), Keppel Street, London, WC1E 7HT, UK. Email: anna.goodman@lshtm.ac.uk. Telephone: 07816066101: Fax: 020 7580 6897

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ABSTRACT

Objectives. To examine whether children compensate for physical activity (the 'activitystat' hypothesis); or alternatively become more active at other times (activity synergy).

Methods. In 2002-2006, 345 British children (8-13 years) completed travel and activity diaries and wore accelerometers. This generated 1077 days of data which we analysed between-children (comparing all days) and within-child (comparing pairs of days from the same child).

Results. On week and weekend days, each extra 1% of time in PE/games, school breaks, school active travel, non-school active travel, structured sports and out-of-home play predicted a 0.21 to 0.60% increase in the proportion of the day in moderate-to-vigorous physical activity (MVPA). None of these behaviors showed evidence of partial compensation at other times (all $p>0.15$). Moreover, each 1% increase in weekday non-school active travel predicted 0.38% more time in MVPA during the rest of the day (95%CI 0.18, 0.58). This activity synergy reflected children using active travel for playing and visiting friends.

Conclusions. Contrary to the 'activitystat' hypothesis, we found no evidence of activity compensation. This suggests that interventions increasing activity in specific behaviors may increase activity overall. The activity synergy of non-school active travel underlines the need for further research into this neglected behavior.

INTRODUCTION

Physical activity in childhood has substantial health benefits throughout life and its promotion is a public health priority (Butland et al., 2007, Department of Health, 2004, Strong et al., 2005, Ekelund et al., 2007). Identifying behaviors contributing substantially to overall activity can help design effective interventions (Tudor-Locke et al., 2006), but requires more detailed information than accelerometers alone can provide (Page et al., 2010).

Detailed behavioral information can also clarify whether children compensate for highly-active periods by being less active at other times. Controversially (Reilly, 2011), this has been hypothesized to reflect the homeostatic action of an ‘activitystat’ in children’s central nervous system (Rowland, 1998, Wilkin et al., 2006, Fremeaux et al., 2011). Some evidence against complete activity compensation is provided by studies indicating that participation in school active travel, sports or play predicts greater overall physical activity (reviewed in Lee et al., 2008, Ferreira et al., 2007, Sallis et al., 2000, Cleland et al., 2008). Detailed behavioral data allows one additionally to examine partial activity compensation (compensation at other times does occur but not enough to negate overall effects) or, alternatively, activity synergy (participation in one active behavior increases activity at other times). Day-by-day behavioral data also permits comparisons of different days within the same child. This addresses the potential limitation of confounding by individual characteristics – for example, children who like physical activity choose to engage in active travel (Lee et al., 2008, Cooper et al., 2003).

This paper therefore seeks to 1) identify the greatest behavioral contributions to overall activity; and 2) examine which behaviors show evidence of activity compensation or activity synergy, including through within-child comparisons.

METHODS

Participants

This paper brings together two observational studies which used the same methods to study 8-13 year olds in Hertfordshire, South-East England (Mackett et al., 2005, Mackett et al., 2007). Eleven schools were selected on the basis of their willingness to co-operate, and children and parents provided written informed assent/consent. The first study (conducted 2002/2003) collected valid data from 194 children in Years 6 and 8 (age 10-11 and 12-13; 50% participation rate). The second study (2005/2006) recruited 151 children from Years 4, 5 and 6 (age 8-11; 55% participation rate). As shown in Table 1, 24% of the 345 participating children were overweight/obese using international cut-points (Cole et al., 2000) and 75% lived in areas less income deprived than the national median (Noble et al., 2004).

The University College London Research Ethics Committee approved these studies.

Child physical activity

We measured physical activity using RT3 tri-axial accelerometers (Stayhealthy Inc, USA). These measure body acceleration in three planes, giving an overall activity count which provides a valid measure of physical activity in children (Rowlands et al., 2004). Accelerometers were worn around the waist on the hip from Wednesday to Monday, giving four full days of data (Thursday to Sunday). Movement was recorded each minute and periods with over 10 continuous minutes of zero counts were considered 'non-worn time'. We measured physical activity as the percentage time spent in moderate-to-vigorous physical activity (MVPA) with a cut-point of 970 counts per minute (Rowlands et al., 2004). As a sensitivity analysis we repeated our analyses using mean overall volume of physical activity (mean counts per minute).

Child behavior

Children completed travel and activity diaries for four days, adapted from National Travel Survey diaries (Kershaw, 2001) and simplified during piloting to ensure children could easily understand them (example extract in Figure 1). Upon completion a researcher went through the diary with the child to clarify parts which were unclear or incomplete (Mackett et al., 2005).

[Insert Figure 1]

We coded the events in these diaries according to a hierarchical typology (Mackett et al., 2005) and grouped them into the following categories: at home; at a friend's home; at another home; school lessons; PE/games; school breaks (including before and after school); clubs and tuition; non-home events (e.g. shopping or meals out, usually with a parent); passive travel (e.g. car, bus); active travel to or from school (e.g. walking, cycling); active non-school travel; structured sport (e.g. sports lessons or training); and out-of-home unstructured play (e.g. informal football games, 'playing'). We calculated percentage duration of each behavior as minutes in that behavior divided by total time.

Statistical analysis

We restricted our analyses to periods with overlapping diary and accelerometer data between 06:00am and 23:00pm, excluding days with <8 hours of overlapping data (N=283) or where a participant was ill (N=20). The result was 1077 valid days, providing an average of 12.2 hours on the 626 weekdays and 11.0 hours on the 451 weekend days.

We investigated activity compensation through both between-child and within-child analyses. Our between-child analyses used linear regression to examine whether each behavior's duration predicted duration of MVPA that day. These analyses adjusted for gender, age, weight status and income deprivation (categorized as in Table 1) and used three-level random intercepts to account for clustering of days within children within schools. We used multiple imputation (25 imputations) to include the 25 children (7%) missing income deprivation data. Our within-child analyses compared pairs of weekdays (Thursday vs. Friday) and pairs of weekend days (Saturday vs. Sunday) within the same child, and examined whether *differences* in each behavior's duration predicted *differences* in MVPA. Within-child analyses used two-level random intercept models to account for clustering of children within schools.

RESULTS

Of the 1077 days included in our analysis, 86% included 60 minutes MVPA (91% in boys, 82% in girls): age, weight status and income deprivation were not associated with MVPA (see Table 1). Our substantive conclusions were similar or identical for boys and girls (see Supplementary Material for sex-stratified results) or when repeated using overall volume of physical activity.

Activity intensity and activity contribution of different behaviors

Table 2 presents each behavior's duration, activity intensity and activity contribution, and Figure 2 summarizes these graphically. Activity intensity was lowest in children's own homes and in school lessons (11-13% time in MVPA), and somewhat higher in other homes (particularly friends' homes), non-home events, clubs/tuition and passive travel (14-29% time in MVPA). PE/games, school breaks, active travel, sports and play showed substantially higher intensity (42-60% time in MVPA). Among these active behaviors, school breaks had the longest duration and therefore made the largest contributors to total daily MVPA (contributing 27% of total weekday MVPA) followed by weekend out-of-home play (contributing 12% of total weekend MVPA). It was notable that children spent less time in active than passive travel on both weekdays (3% vs. 4%) and weekends (3% vs. 9%); activity intensity during passive travel was under half that during active travel.

[Insert Table 2 and Figure 2]

Activity compensation and activity synergy

Columns 1 and 2 of Table 3 provide evidence against complete activity compensation for time at home or in lessons or. Instead each extra 1% of the child's day spent in these settings was associated with a 0.06% to 0.15% decrease in the proportion of that day spent in MVPA. Conversely, each extra 1% of the child's day spent in PE/games, school breaks, active travel, structured sports and play was associated with a 0.21% to 0.60% increase in the proportion of the day spent in MVPA. These associations were usually replicated in within-child analyses (column 2) except for school active travel in which the comparison appeared to be underpowered due to low variation between pairs of days. The effect sizes were also little changed in multivariable analyses adjusting for time spent in other behaviors (see Supplementary Material), indicating that these highly-active behaviors had largely independent effects.

[Insert Table 3]

Columns 3 and 4 of Table 3 examine partial activity compensation and activity synergy by presenting the effect of each behavior's duration upon MVPA at other times. The only indication of partial activity compensation was evidence that each extra 1% time spent at home on weekends (i.e. an inactive setting) predicted a 0.14% (between-child)/0.17% (within-child) increase in the proportion of MVPA during the rest of the day. There was no suggestion of partial activity compensation for spending more time in PE/games, school breaks, active travel, sports or play. On the contrary, the trend was usually for longer participation in these behaviors to be associated with a *higher* proportion of MVPA at other times – i.e. a trend towards activity synergy.

The strongest and most consistent evidence of activity synergy was for non-school active travel on weekdays. Each extra 1% time spent in non-school active travel predicted a 0.38% (between-child)/0.36% (within-child) increase in proportion time in MVPA during the rest of the day. The replication of this effect in within-child analyses indicates that it cannot be explained by individual-level confounders but may instead reflect non-school active travel facilitating other active behaviors. Figure 3 examines this by comparing time spent in different behaviors according to whether the day included any non-school active travel. Both week and weekend days including non-school active travel involved less time at home or in passive travel and more time in friends' homes, school active travel and play. This was further supported by examining the travel modes associated with different behaviors. Overall children made fewer than half their journeys by active modes (49% active modes on weekdays, 28% on weekends). The highest proportion of active modes was seen for trips to friends' homes (68% weekdays, 40% weekends) and out-of-home play (57% weekdays, 40% weekends). Active travel modes were less common for trips to other homes (28% weekdays, 16% weekends), non-home events (32% weekdays, 23% weekends), clubs and tuition (41% weekdays, 18% weekends) and, particularly on weekends, structured sports (37% weekdays, 10% weekends).

[Insert Figure 3]

DISCUSSION

In this sample of 345 8-13 year olds, school breaks and out-of-home play made particularly large contributions to total daily MVPA, reflecting the comparatively large proportion of children's time spent in these behaviors. Higher overall physical activity was also independently predicted by time spent in PE/games lessons, school active travel, non-school active travel and structured sports. None of these behaviors showed evidence of activity compensation but children using non-school active travel on weekdays were more active at other times. This activity synergy reflected the use of active travel for playing and visiting friends. Almost all results were very similar in between-child and within-child analyses, providing evidence against substantial confounding by individual characteristics.

From a public health perspective, identifying major contributors to overall activity is important because small relative changes may have disproportionately large effects upon the population mean. The substantial contribution of school breaks is consistent with previous studies (Ridgers et al., 2006, Tudor-Locke et al., 2006), and adds to the evidence that schools should protect and enhance the potential of break times to promote physical activity. As for children's play, its potential activity contribution has recently become the focus of increased attention by policy-makers (DCSF, 2008), an attention which our findings support.

None of the physically active behaviors we evaluated showed evidence of activity compensation. Previous observational and experimental investigations of activity compensation/the 'activitystat' hypothesis have produced mixed findings (reviewed in Reilly, 2011). Our findings are, however, in line with the largest observational study to date (Baggett et al., 2010) and also consistent with reviews of observational studies of time spent in behaviors like active travel (Lee et al., 2008, Ferreira et al., 2007, Sallis et al., 2000). Intervention studies would be needed to confirm this, particularly as some trials have reported activity increases during PE/games classes but not overall (van Sluijs et al., 2007). On the other hand, a similar more recent finding seemed simply to reflect reduced statistical power for non-specific outcomes like overall activity (Kriemler et al., 2010). Our conclusions are therefore provisional but encouraging, suggesting that interventions increasing time spent in PE/games, school breaks, school/non-school active travel, sport or play may translate into increased overall physical activity. The largely independent nature of these effects further indicates that targeting multiple behaviors might have an even greater impact, as well as capitalising upon these behaviors' distinctive physical and psychosocial benefits (Page et al., 2010).

One such benefit is the apparent synergy between non-school active travel and other active behaviors. Non-school active travel has been little studied (Lubans et al., 2011); to our knowledge this is the first demonstration that it predicts total weekday physical activity, and that it does so independently of school active travel. Our findings further suggest that this activity synergy reflects children using active travel to leave their (low activity) homes to play or visit friends' homes. This extends previous analyses of questionnaires from a subsample of our study population, in which children allowed to go out alone were more likely to report 'often' going outdoors or visiting friends (Mackett et al., 2007). This is consistent with mounting evidence that children's independent mobility enables other active behaviors (Wen et al., 2009, Page et al., 2010) and suggests a mechanism underlying the previously observed association between school active travel and evening physical activity (Cooper et al., 2003). Children's active travel to play sessions also contrasts with their predominantly passive travel to structured sports. This supports the importance of providing safe routes to play spaces (DCSF, 2008) and indicates wider potential health and environmental benefits of promoting unstructured physical activity (Hjorthol and Fyhri, 2009).

Besides these empirical findings, we believe our paper makes a methodological contribution. In examining the issue of activity compensation we 1) directly examined physical activity at other times and 2) used within-child analyses to replicate between-child findings, thereby addressing confounding by individual characteristics such as activity preferences. To our knowledge these approaches are novel in this field, probably reflecting the high participant burden associated with collecting detailed, day-by-day behavioral information. Our methods may have wider applicability in the future, however, as researchers increasingly generate behavioral data indirectly from devices such as Global Positioning System (GPS) receivers (Jones et al., 2009, Cooper et al., 2010, Troped et al., 2008).

Limitations

Although our fine-grained behavior data was a key strength, children will inevitably have made mistakes in recording activity timings and durations. This measurement error means we are likely to have underestimated the activity intensity and activity contributions of the high-active behaviors and overestimated those of the low-activity behaviors. We also failed to ask participants to record separately behaviors such as TV viewing or computer gaming, and therefore could not examine activity contributions and compensation with respect to sedentary behaviors.

Furthermore our participants came from only one, relatively low-deprivation region of England. This may limit generalizability, although it is worth noting that deprivation did not predict physical activity and that participants' body composition was similar to the national average (mean BMI=18.7 vs. 19.1 among 8-13 year olds nationally 2002-2006 (Health Survey for England, 2008)). Moreover, given the hypothesized universality of the activitystat (Wilkin et al., 2006), we believe this study is valuable even if it is only treated as providing local evidence against activity compensation.

CONCLUSIONS

In British 8-13 year olds, school breaks and out-of-home play made particularly large contributions to total activity, but there were also independent effects from PE/games, school active travel, non-school active travel and sports. Children showed no evidence of activity compensation for these behaviors, an encouraging finding for targeted behavioral interventions. Moreover, non-school active travel (a hitherto neglected behavior) showed activity synergy with visiting friends and play. Complementing traditional analyses with within-child comparisons proved a valuable methodological approach, which we recommend to future studies seeking to extend these empirical findings.

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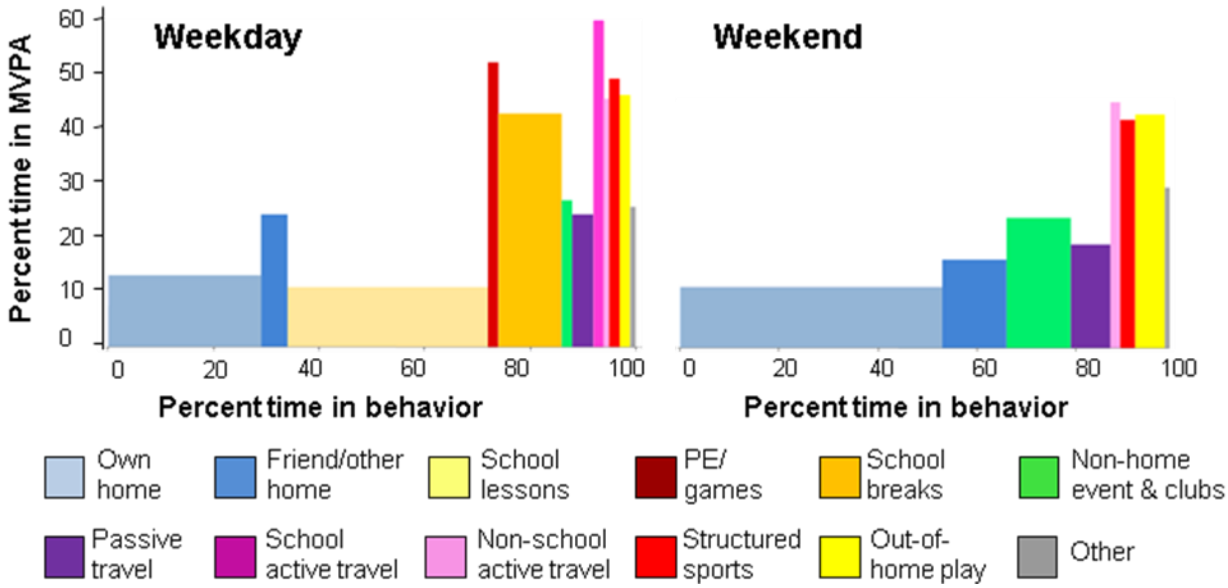
FIGURE LEGENDS

Figure 1: Example extract of travel and activity diary

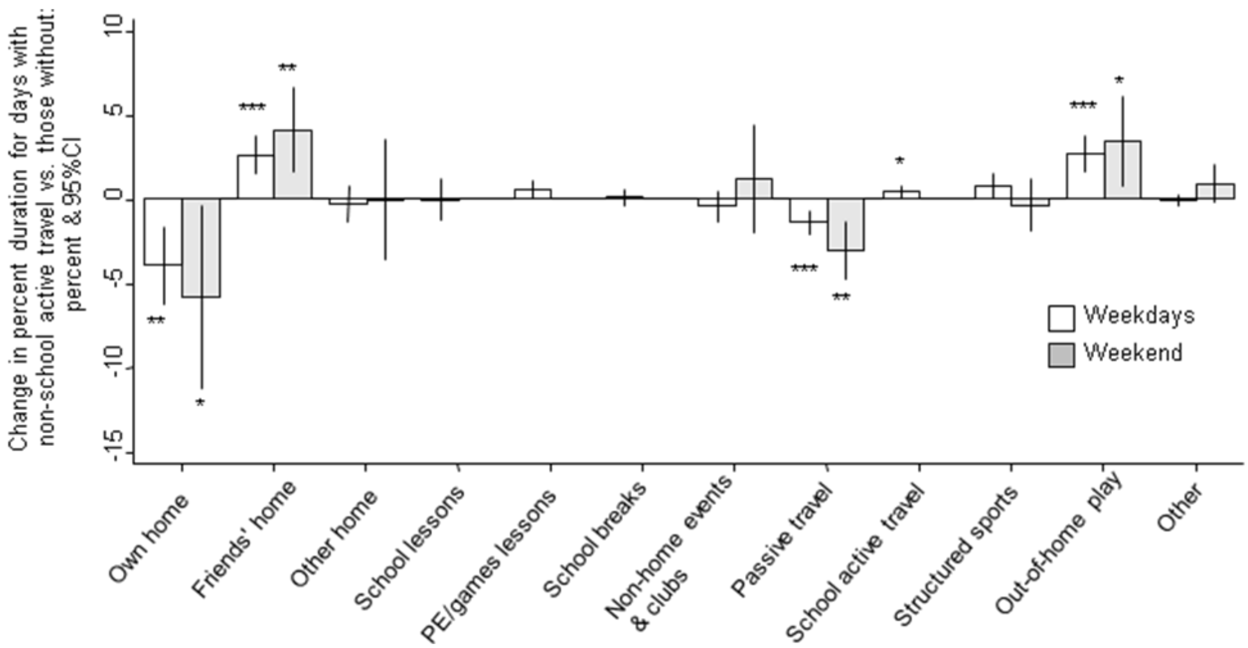
[TO GET FROM ROGER]

Figure 2: Percentage duration and physical activity intensity in each behavior



N=626 weekdays, 451 weekend days: from 345 children aged 8-13 in South-East England, collected 2002-2006.

Figure 3: Difference in duration of each behavior between days with and without non- school active travel



*p<0.05, **p<0.01, *** p<0.001 for difference, with positive differences indicating longer duration on days with non-school active travel Differences based on percent durations calculated after removing any minutes of the day spent in non-school active travel. N=626 weekdays, 451 weekend days: from 345 children aged 8-13 in South-East England, collected 2002-2006. Data tabulated in the Supplementary Material

TABLES

Table 1: Demographic characteristics of study participants

		Children		Valid study days			
		N	**Percent of all children**	**N**	**Percent of all days**	**Percent days with ≥60 min. MVPA**	**P-value for difference†**
Full sample		345	100%	1077	100%	86%	-
Study	Study 1 (2002-3)	194	56%	685	64%	87%	0.64
	Study 2 (2005-6)	151	44%	392	36%	85%	
Gender	Male	161	47%	509	47%	91%	<0.001
	Female	184	53%	568	53%	82%	
Age	8-9	85	24%	229	21%	87%	0.61
	10-11	178	52%	555	52%	86%	
	12-13	82	24%	293	27%	82%	
Weight status	Normal/underweight	263	76%	826	77%	86%	0.71
	Overweight	63	18%	197	18%	88%	
	Obese	19	6%	54	5%	81%	
Small-area income deprivation††	Quarter 1 (least deprived)	169	53%	571	56%	86%	0.96
	Quarter 2	80	25%	228	22%	86%	
	Quarter 3	54	17%	170	17%	86%	
	Quarter 4 (most deprived)	17	5%	52	5%	85%	

MVPA= moderate-to-vigorous physical activity. Data collected in South-East England in 2002-2006. †Calculated from univariable linear regression, adjusting for clustering of days within individuals within schools. ††Assigned using 2004 Indices of Multiple Deprivation (Noble et al. 2004), quarters defined with reference to the whole of England. Numbers for this variable add to less than 345 because of missing data (N=25): multiple imputation used to include all children in regression analyses.

Table 2: Duration, activity intensity and activity contribution of each behaviour

		Duration: Proportion of day spent in behaviour		**Activity intensity: Proportion of behaviour spent in MVPA**		**Activity contribution: Proportion of total daily MVPA contributed by behaviour**	
		Percent	SE	Percent	SE	Percent	SE
Week day	Own home	30%	(0.6)	13%	(0.5)	18%	(0.6)
	Friend's home	3%	(0.3)	28%	(2.3)	3%	(0.3)
	Other home	2%	(0.3)	17%	(1.7)	2%	(0.3)
	School Lessons	39%	(0.4)	11%	(0.3)	22%	(0.5)
	PE/games	2%	(0.1)	52%	(2.0)	4%	(0.3)
	School breaks	12%	(0.1)	43%	(1.0)	27%	(0.6)
	Clubs & tuition	1%	(0.2)	23%	(2.3)	1%	(0.2)
	Non-home events	1%	(0.2)	29%	(2.4)	2%	(0.2)
	Passive travel †	4%	(0.2)	24%	(0.9)	5%	(0.3)
	School active travel †	2%	(0.1)	60%	(1.4)	7%	(0.4)
	Non-school active travel†	1%	(0.1)	46%	(2.3)	2%	(0.2)
	Structured sport	1%	(0.2)	49%	(2.9)	3%	(0.4)
	Out-of-home play	3%	(0.3)	46%	(2.7)	5%	(0.5)
	Other	0%	(0.1)	26%	(3.6)	1%	(0.1)
Week-end	Own home	53%	(1.6)	11%	(0.5)	38%	(1.6)
	Friend's home	5%	(0.7)	20%	(2.3)	5%	(0.8)
	Other home	9%	(1.1)	14%	(1.1)	8%	(1.0)
	Clubs & tuition	0%	(0.1)	20%	(4.7)	0%	(0.2)
	Non-home events	12%	(0.8)	24%	(1.3)	15%	(1.1)
	Passive travel †	8%	(0.5)	19%	(1.0)	9%	(0.5)
	Non-school active travel †	2%	(0.3)	45%	(2.2)	6%	(0.6)
	Structured sport	3%	(0.4)	42%	(3.3)	5%	(0.8)
	Out-of-home play	7%	(0.7)	43%	(2.2)	12%	(1.1)
	Other	1%	(0.3)	29%	(3.2)	2%	(0.4)

†Most time in passive travel was spent in cars (89% on weekdays, 96% on weekend days) and most time in active travel was spent in walking (98% of school active travel, 81% of weekday non-school active travel, 70% of weekend non-school active travel). MVPA= moderate-to-vigorous physical activity, SE=robust standard error. Data from 345 children aged 8-13 in South-East England, collected 2002-2006. N=626 weekdays, 451 weekend days. The Supplementary Material presents sex-stratified results and also shows the distribution of each behaviour across the day.

Table 3: Association between time spent in different behaviours and volume of physical activity

		Regression coefficients (95% CI) for effect of percent duration of behaviour upon percent time in MVPA...			
		...1) across the whole day (complete activity compensation)		...2) at other times (partial activity compensation or, alternatively, activity synergy)	
		Between-child [a]	**Within-child [b]**	**Between-child [a]**	**Within-child [b]**
Week	Own home	-.14 (-.18, -.09)***	-.15 (-.21, -.09)***	-.02 (-.07, .03)	-.05 (-.12, .02)
	Friend's home	.09 (.01, .18)*	.01 (-.10, .12)	.11 (.02, .21)*	.02 (-.09, .13)
	Other home	-.06 (-.16, .04)	-.02 (-.15, .11)	.01 (-.09, .11)	.04 (-.09, .18)
	School lessons	-.12 (-.21, -.04)**	-.14 (-.26, -.02)*	.14 (.02, .25)*	.06 (-.11, .23)
	PE/games	.53 (.36, .70)***	.41 (.22, .61)***	.23 (.07, .40)**	.17 (-.04, .37)
	School breaks	.25 (.03, .47)*	.28 (.00, .55)*	.03 (-.19, .25)	-.01 (-.31, .29)
	Clubs & tuition	-.08 (-.25, .09)	.04 (-.15, .24)	-.16 (-.33, .01)	-.05 (-.24, .15)
	Non-home events	.04 (-.10, .19)	-.04 (-.21, .13)	-.01 (-.15, .13)	-.09 (-.25, .08)
	Passive travel	-.12 (-.26, .02)	-.11 (-.30, .08)	-.07 (-.21, .08)	-.05 (-.24, .15)
	School active travel	.56 (.27, .86)***	.04 (-.41, .50)	.22 (-.08, .52)	-.31 (-.77, .15)
	Non-school active travel	.60 (.39, .80)***	.52 (.23, .82)***	.38 (.18, .58)***	.36 (.07, .66)*
	Structured sport	.29 (.15, .43)***	.32 (.15, .48)***	.03 (-.11, .17)	.06 (-.10, .23)
	Out-of-home play	.26 (.17, .36)***	.30 (.19, .41)***	.08 (-.02, .17)	.12 (.01, .22)*
	Other	-.09 (-.38, .21)	-.05 (-.38, .29)	-.24 (-.54, .05)	-.21 (-.54, .13)
Week -end	Own home	-.10 (-.13, -.07)***	-.06 (-.10, -.02)**	.14 (.08, .20)***	.17 (.07, .26)**
	Friend's home	.03 (-.03, .10)	.03 (-.05, .11)	-.01 (-.08, .06)	-.02 (-.11, .07)
	Other home	-.05 (-.09, .00)	-.11 (-.18, -.04)**	-.02 (-.07, .03)	-.07 (-.15, .01)
	Clubs & tuition	.00 (-.30, .30)	-.03 (-.39, .33)	-.06 (-.36, .23)	-.11 (-.47, .24)
	Non-home events	.01 (-.05, .06)	-.03 (-.10, .03)	-.04 (-.10, .01)	-.08 (-.15, -.01)*
	Passive travel	-.04 (-.13, .06)	-.10 (-.22, .02)	.00 (-.10, .10)	-.07 (-.20, .06)
	Non-school active travel	.35 (.19, .50)***	.25 (.05, .45)*	.07 (-.08, .23)	-.09 (-.29, .11)
	Structured sport	.28 (.18, .37)***	.30 (.18, .41)***	.03 (-.07, .12)	.04 (-.08, .15)
	Out-of-home play	.26 (.20, .32)***	.21 (.14, .29)***	.06 (.00, .12)	.00 (-.08, .07)
	Other	.10 (-.05, .26)	.01 (-.21, .24)	-.02 (-.18, .13)	-.04 (-.26, .18)

*p<0.05, **p<0.01, *** p<0.001. CI=confidence interval, MVPA= moderate-to-vigorous physical activity. Data from 345 children aged 8-13 in South-East England, collected 2002-2006. Between-child analyses across all days (N=626 weekdays, 451 weekend days), within-child analyses across pairs of days within the same child (N=284 weekday pairs, 185 weekend day pairs). [a] Adjusted for gender, age, weight status and income deprivation: see Supplementary Material for models which adjust for time spent in other behaviours. [b] univariable analyses.