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Compensation of Physical Activity and Sedentary Time in Primary School Children

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ABSTRACT

RIDGERS, N. D., A. TIMPERIO, E. CERIN, and J. SALMON. Compensation of Physical Activity and Sedentary Time in Primary School Children. *Med. Sci. Sports Exerc.*, Vol. 46, No. 8, pp. 1564–1569, 2014. **Purpose**: There is considerable debate about the possibility of physical activity compensation. This study examined whether increased levels in physical activity and/or sedentary behavior on 1 d were predictive of lower levels in these behaviors on the following day (compensatory mechanisms) among children. **Methods**: Two hundred and forty-eight children (121 boys and 127 girls) age 8–11 yr from nine primary schools in Melbourne, Australia, wore a GT3X+ ActiGraph for seven consecutive days. Time spent in light physical activity (LPA) and moderate- to vigorous-intensity physical activity (MVPA) was derived using age-specific cut points. Sedentary time was defined as 100 counts per minute. Meteorological data (temperature, precipitation, relative humidity, and daylight hours) were obtained daily and matched to accelerometer wear days. Multilevel analyses (day, child, and school) were conducted using generalized linear latent and mixed models. **Results**: On any given day, every additional 10 min spent in MVPA was associated with approximately 25 min less LPA and 5 min less MVPA the following day. Similarly, additional time spent in LPA on any given day was associated with less time in LPA and MVPA the next day. Time spent sedentary was associated with less sedentary time the following day. Adjusting for meteorological variables did not change observed compensation effects. No significant moderating effect of sex was observed. **Conclusion**: The results are consistent with the compensation hypothesis, whereby children appear to compensate their physical activity or sedentary time between days. Additional adjustment for meteorological variables did not change the observed associations. Further research is needed to examine what factors may explain apparent compensatory changes in children's physical activity and sedentary time. **Key Words:** ACTIVITYSTAT, YOUTH, ACCELEROMETRY, SEDENTARY BEHAVIOR

Physical activity has numerous physical, social, and mental health benefits (17). Several countries, such as the United States, Australia, and Canada recommend that children should engage in at least 60 min of moderate- to vigorous-intensity physical activity (MVPA) every day to benefit health (10,32,37). However, population estimates indicate that only 22% of boys and 20% of girls age 9–11 yr old meet these recommendations in Australia (3), whereas in the United States, 49% of boys and 35% of girls accumulated at least 60 min of MVPA (33). Consequently, there is a need to identify interventions and strategies that effectively increase children's engagement in physical activity to benefit health outcomes. A wide range of interventions have been implemented in several settings, including schools, the family environment, primary care, and local community settings, but efficacy in the short and long term has greatly varied (20,31,39).

One potential explanation for the varied efficacy of interventions is the "activitystat" hypothesis, which suggests that children compensate for increased physical activity in one part of the day by decreasing their physical activity in another part of the day to maintain an innate total physical activity set point (27). In the context of physical activity interventions, compensation may be indicated when strategies show potential in increasing physical activity in particular domains, but have limited effects on overall daily physical activity.

There is considerable debate concerning the existence and nature of an activitystat (24,40), with mixed findings reported in the literature to date. Observational research using between-person designs has reported that children who have different opportunities for physical activity participation during the school day engage in similar total daily volumes of physical activity (12,41). However, as the "activitystat" hypothesis is a within-person hypothesis, within-subject designs are needed (18). A recent review noted that 63% of experimental studies that specifically examined this hypothesis in children reported physical activity compensation (13), although because a range of interventions were delivered across multiple time frames and different settings, no clear conclusions could be drawn concerning the activitystat hypothesis (13). In contrast,

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observational and experimental studies that have used within-person designs to explore within- and between-day compensation have found no evidence of compensatory changes (4,9). Indeed, some studies have indicated that activity synergy may occur, where participation in an active behavior increases activity at other times of the day (8,14,18). Although some of these studies adjust for sociodemographic variables, such as age, sex, and social deprivation (4,14,18), meteorological variables that may affect day-to-day or within-day variation in physical activity to date have not been controlled for. Past research has shown that length of the day and weather effects (e.g., rainfall, temperature) are associated with physical activity (7,15), and that daily fluctuations in such variables may affect spontaneous and unplanned physical activity behaviors (5).

Furthermore, if children maintain close regulatory control over their physical activity engagement, as is hypothesized by "activitystat," changes in participation in physical activity at different intensities and in sedentary time would be expected to occur after activity engagement (27). To date, most studies have focused on compensatory changes of MVPA on MVPA elsewhere in the day or across the whole day (8,9,12,14,18,41) and have not accounted for person-level activity, around which activity may fluctuate. In addition, with only one exception (4), these studies typically have not examined potential compensatory effects on other intensities of physical activity (such as light-intensity physical activity) or sedentary time. This is important to explore as all intensities would contribute to a daily activity set point (27). In addition, as the "activitystat" hypothesis is considered to be a homeostatic mechanism, it is possible that the set point may differ between girls and boys, which may have implications for the development of targeted physical activity interventions.

The aim of this study, therefore, was to examine whether children's physical activity and sedentary time on 1 d was associated with their activity levels the following day after adjusting for person-level and meteorological variables. It was hypothesized that (a) children who engage in more physical activity on 1 d would be less active the following day (across all intensities), and (b) children who spent more time sedentary on 1 d would decrease their sedentary time the following day. A secondary aim was to explore whether these associations differed between boys and girls.

METHOD

Participants

Baseline data were taken from a longitudinal study of physical activity and sedentary behavior among primary school children: the Patterns of Habitual Activity across Seasons Study. Primary schools with enrolments greater than 200 pupils located within a 40-km radius of the Melbourne Central Business District were stratified into tertiles of socioeconomic status (SES) using the Socio-Economic Index for Areas (2). Schools were randomly selected from each SES strata and invited to participate in the study. Nine schools (one low SES, three medium SES, and five high SES) agreed to participate in the study. Ethical approval was provided by the Deakin University Human Ethics Advisory Group (Health), the Department of Education and Early Childhood Development, and the Catholic Education Office (Melbourne).

Once informed consent had been obtained from the school principal, all children in grades 4 and 5 (age 8–11 yr) were invited to participate in the study (n = 1270). Informed written parental consent was provided for 326 children (162 boys, 164 girls; 26% response rate) to participate in at least one component of the study. Three hundred and eleven children (156 boys and 155 girls) wore accelerometers at baseline in August and September 2012 (Winter school term).

Measures

Physical activity. Children's physical activity levels and sedentary time were measured for seven consecutive days using a hip-mounted ActiGraph model GT3X+ (Pensacola, FL). Acceleration data were sampled by a 12-bit analog converter at a user-specified rate (30–100 Hz) and stored in the nonvolatile flash memory (1). In this study, raw triaxial acceleration data were sampled at 30 Hz. Children were instructed to wear the monitor during all waking hours except during water-based activities (e.g., swimming and bathing) and were provided with information concerning the correct wear and care of the monitor. The ActiGraph has acceptable reliability and validity in pediatric populations (35).

Meteorological information. Data concerning the maximum temperature (°C), total rainfall (mm), minutes of daylight, and average relative humidity (%) were obtained on each day of data collection from the publicly accessible Bureau of Meteorology website (www.bom.gov.au/vic). This information was obtained from the weather station located nearest to each school and matched to accelerometer wear days.

Anthropometry. Body mass was measured to the nearest 0.1 kg using a calibrated electronic scale (Tanita BC-351; Tanita, Japan). Stature was measured to the nearest 0.1 cm using SECA portable stadiometers (model 217; SECA, Germany). Waist circumference (to the nearest mm) was measured using a flexible steel tape at the narrowest point between the bottom rib and the iliac crest, in the midaxillary plane. Two measurements of body mass, stature, and waist circumference were taken. In the event of a discrepancy over 0.1 kg, 0.1 cm, and 1 cm for body mass, stature, and waist circumference, respectively, a third measure was taken. Body mass index (BMI, $kg \cdot m^{-2}$) was also calculated. All measurements were taken by trained research staff using standardized procedures.

Accelerometer Data Reduction

ActiGraph data were downloaded and processed into 15-s epochs using ActiLife (version 6.5.2). Data were then processed

EPIDEMIOLOGY

TABLE 1. Descriptive data from included participants (mean ± SD).

	Boys (n = 121)	Girls (n = 127)	Whole Sample (n = 248)
Age (yr)	10 ± 0.7	10.1 ± 0.7	10 ± 0.7
Stature (cm)	143.9 ± 7.2	142.3 ± 7.5	143.1 ± 7.4
Body mass (kg)	38.6 ± 9.3	37.8 ± 8.8	38.2 ± 9.1
Waist circumference (cm)	69.2 ± 10.3	68.3 ± 9.2	68.8 ± 9.7
BMI (kg·m^{-2})	18.5 ± 3.1	18.5 ± 3.2	18.5 ± 3.1
ActiGraph data			
Sedentary time (min·d^{-1})	459.9 ± 144.3	507.0 ± 146.1	484 ± 146.8
Light-intensity physical activity (min·d^{-1})	250.6 ± 43.9	261.3 ± 45.6	256.1 ± 45
MVPA (min·d^{-1})	84.9 ± 25	67.6 ± 21	76.1 ± 24.6
Wear time (min·d^{-1})	795.4 ± 153.5	835.9 ± 176	816.2 ± 166.3

using a customized Excel macro. Nonwear time was defined as intervals with at least 20 min of consecutive zeros, which is the most commonly used nonwear definition in children (6). The total duration of these periods represented the duration of total nonwear time. A valid day was defined as ≥8 h on weekdays and ≥7 h on weekend days (19). To be included in the analyses, children were required to have worn the ActiGraph on at least 3 d.

Age-specific cut points (11) were used to identify the time spent in light- (LPA, ≥1.5 to 3.99 METs), moderate- (MPA, 4–5.99 METs), and vigorous (VPA, ≥6 METs)-intensity physical activity. A threshold of 4 METs was chosen to represent MPA because brisk walking has been associated with an energy cost of 4 METs in calibration studies (34). MPA and VPA were summed to obtain MVPA. Sedentary time was defined as ≤100 counts per minute (26).

Statistical Analyses

Descriptive statistics (mean ± SD) were initially calculated for all measured variables. To account for the nested nature of the data (multiple physical activity data collected within the same days nested within participants nested within schools), multilevel analyses were conducted using the generalized linear latent and mixed models (GLLAMM) procedure (23). Multilevel models are the most appropriate technique for analyzing nested data that are not independent of each other (36). Initial GLLAMM was conducted to examine differences between children with complete and incomplete accelerometry data with adjustment for clustering at the school level.

Three sets of GLLAMM were estimated in the main analyses. The first set examined associations of temporally adjacent values (pairs of days) on physical activity and/or sedentary time variables (e.g., MVPA on day d with MVPA on day $d-1$) without adjustment for person-level physical activity and/or sedentary time (as appropriate) and meteorological conditions. Because the data were collected for seven consecutive days, each child provided six data points (e.g., day 2 (d) compared with day 1 ($d-1$)). The analyses examined whether the activity level a child engaged in on a subsequent day (day d in the model) was associated with their activity during the previous day (day $d-1$ in the model). In all models, the random structure considered random intercepts at the school and person levels and random slopes for the physical activity and/or sedentary time variables at $d-1$ at the person level. The second set of GLLAMM estimated the above associations while adjusting for person-level physical activity and/or sedentary time. Unlike statistical approaches taken to examine compensation in the past, these GLLAMM can separate person-level effects from day-level (i.e., within-person changes) effects and are therefore a more appropriate measure of compensation. The associations produced by the first set of GLLAMM represent a mix of person- and day-level effects and, thus, do not correctly quantify within-subject compensatory processes. Finally, a third set of GLLAMM examined the confounding effects of meteorological conditions on compensation processes. That is, we examined the extent to which the magnitude of the compensation processes observed in the second set of models would change after the inclusion of meteorological predictors (i.e., temperature, rainfall, humidity, and daylight minutes) in the GLLAMM. A sizeable reduction in estimates of compensation processes (regression coefficients) would be indicative of meteorological conditions being responsible for the observed compensation effects. A three-level model was used in all these analyses, namely, day (level 1), children (level 2) and school (level 3). All sets of models were adjusted for sex, grade, day of measurement, waist circumference, and wear time on a given day. The potential moderating effect of sex on observed associations were estimated in all three sets of models by including appropriate interaction terms. A two-tailed probability level of 0.05 was adopted. All analyses were conducted in Stata SE version 12 (StataCorp LP, College Station, TX).

RESULTS

Two hundred and forty-eight children (121 boys and 127 girls) met the inclusion criteria and were included in the analyses. Descriptive data for the children are presented in Table 1. There were no significant differences in age and stature between children included and excluded from the analyses, although the excluded children had significantly higher body mass (4.1 kg, P = 0.04), waist circumference (4.7 cm, P = 0.02), and BMI (1.6 kg·m^{-2}, P = 0.02) than the included children.

The interaction terms revealed no significant moderating effect of sex in all three sets of models (all P > 0.05, data not shown). Consequently, associations are presented for the whole sample (Table 2). Overall, six significant associations

TABLE 2. Associations between time (min) spent in different physical activity intensities and sedentary time variables between pairs of days.

	Model 1[a]		Model 2[b]		Model 3[c]	
	b (95% CI)	*P* Value	*b* (95% CI)	*P* Value	*b* (95% CI)	*P* Value
$MVPA_{D1} \rightarrow MVPA_{D2}$	−0.22 (−0.54 to 0.01)	0.175	−0.55 (−0.80 to −0.29)	<0.001	−0.50 (−0.76 to −0.24)	<0.001
$LPA_{D1} \rightarrow LPA_{D2}$	−0.27 (−0.37 to −0.17)	<0.001	−0.45 (−0.54 to −0.37)	<0.001	−0.46 (−0.54 to −0.38)	<0.001
$SED_{D1} \rightarrow SED_{D2}$	0.07 (0.04 to 0.11)	<0.001	−0.04 (−0.08 to −0.01)	0.014	−0.05 (−0.08 to −0.01)	0.009
$LPA_{D1} \rightarrow MVPA_{D2}$	−0.05 (−0.11 to 0.01)	0.107	−0.10 (−0.15 to −0.05)	<0.001	−0.09 (−0.14 to −0.04)	0.001
$SED_{D1} \rightarrow MVPA_{D2}$	−0.01 (−0.02 to 0.01)	0.143	0.01 (−0.01 to 0.02)	0.365	0.01 (−0.01 to 0.02)	0.134
$MVPA_{D1} \rightarrow LPA_{D2}$	−0.84 (−1.31 to −0.37)	0.001	−2.42 (−2.85 to −1.99)	<0.001	−2.49 (−2.91 to −2.06)	<0.001
$LPA_{D1} \rightarrow SED_{D2}$	0.31 (0.18 to 0.44)	<0.001	−0.06 (−0.19 to 0.07)	0.347	−0.07 (−0.19 to 0.06)	0.296
$MVPA_{D1} \rightarrow SED_{D2}$	1.07 (0.41 to 1.73)	0.001	−1.29 (−1.99 to −0.59)	<0.001	−1.38 (−2.10 to −0.66)	<0.001
$SED_{D1} \rightarrow LPA_{D2}$	−0.05 (−0.08 to −0.03)	<0.001	−0.05 (−0.08 to −0.03)	<0.001	−0.02 (−0.04 to 0.01)	0.175

[a]Model 1: Adjusted for sex, grade, day of measurement (Monday, Tuesday, etc.), waist circumference, and wear time on a given day.
[b]Model 2: Additionally adjusted for average person-level physical activity and/or sedentary time (as appropriate) per day.
[c]Model 3: Additionally adjusted for temperature, rainfall, humidity, daylight minutes.
SED, sedentary time; *b*, point estimate of the regression coefficient.

between temporally adjacent values on physical activity and sedentary time variables were observed in model 1, five of which remained significant after adjusting for person-level physical activity and/or sedentary time in model 2. Two further significant negative associations were identified in model 2 between MVPA on 1 d and MVPA the following day ($P < 0.001$), and LPA on a given day and MVPA the following day ($P < 0.001$).

All associations observed in model 2 remained significant after adjusting for meteorological variables (model 3), with the exception of sedentary time on a given day and LPA the following day. On any given day, every additional 10 min spent in MVPA was associated with approximately 25 min less LPA ($P < 0.001$) and 5 min less MVPA ($P < 0.001$) the following day. Similarly, on any given day, every additional 10 min spent in LPA was associated with approximately 4.6 min less LPA ($P < 0.001$) and 0.9 min less MVPA the following day ($P = 0.001$). Lastly, every additional 10 min spent in sedentary time on any given day was associated with 0.5 min less sedentary time the following day ($P = 0.009$).

DISCUSSION

This study tested the concept of an "activitystat" hypothesis by examining associations between time spent in different physical activity intensities and/or sedentary time on any given day and time spent in these activities the following day. The findings indicated that once person-level effects were accounted for in the analyses, children seemed to compensate their activity levels between days. Only small changes in the strength of these observed associations were observed when the meteorological variables were included in the analyses.

In this study, negative associations were found between time spent in MVPA and LPA on a given day and physical activity accumulated on the following day. This suggests that for every additional minute of physical activity, children engaged in less physical activity (e.g., LPA) the following day, which is consistent with the "activitystat" hypothesis (27) whereby individuals compensate for increased physical activity levels on 1 d by decreasing their activity levels the following day. These findings contrast previous research conducted in youth that have not found evidence of compensatory changes in activity within or between days when assessed using accelerometers (4,9,14,18). It should be noted, however, that these studies did not adjust for person-level mean physical activity, which may explain the differences observed between the findings. In the present study, the compensation of physical activity was typically evident once the analyses were adjusted for person-level activity levels. The only finding that was not consistent with the "activitystat" hypothesis was the negative association that was found between MVPA on a given day and sedentary time the following day. This finding is difficult to explain. In the context of the "activitystat" hypothesis, a positive association would be anticipated where individuals compensate for higher levels of MVPA on 1 d by engaging in more sedentary time as well as reducing MVPA on the next day. It is possible that this is a spurious finding, and further research is needed to examine the associations between MVPA and sedentary time across days.

To the best of our knowledge, this is the first study to examine associations between different physical activity intensities and/or sedentary time to investigate compensatory changes in children's activity between days. Negative associations were observed for less intensive physical activity (i.e., LPA) with subsequent LPA and MVPA, and for sedentary time on any given day and sedentary time the following day. These findings suggest that compensatory effects occur across different physical activity intensities, which is consistent with the "activitystat" hypothesis. This is important to note, particularly because in recent years, there has been increasing interest in the reduction of sedentary time through the promotion of light-intensity activities such as standing (16,30). Although some of the observed associations between intensities were small, the compensatory changes that were observed between intensities were consistent with the hypothesis that all activities would contribute to an individual's set point (27). However, it is currently unknown how these intensities contribute to a hypothesized set point and the threshold at which compensatory responses may occur (24,40), which has implications for the development of future interventions. Experimental studies are needed to examine this further.

Although the findings above are consistent with the "activitystat" hypothesis, it does not necessarily mean that interventions aiming to increase children's physical activity levels are destined to fail (24,28). Arguably, these findings have implications for the design of future interventions and provide an insight into potential strategies that could be implemented. For example, strategies may need to be implemented to negate compensatory responses to physical activity engagement across different intensities. Indeed, consistent exposure to the intervention may be needed to yield significant changes, and interventions may need to target multiple intensities of physical activity on every day to reduce compensatory changes and increase total physical activity. Further research is needed to establish the effectiveness of such strategies on children's physical activity levels.

Our study is the first to examine moderating effects of sex on compensation between different intensities of physical activity and sedentary time across days. However, no evidence of differential physical activity compensation between boys and girls was found. This is consistent with prior research examining compensation associated with MVPA and total physical activity within and between days (18,21,22) and across different settings (41). Despite the literature consistently reporting that boys are more active than girls across the whole day (29,38) and within specific periods of the day (e.g., recess (25)), the findings from the present study suggest that compensatory changes in activity between days does not appear to differ between boys and girls. To date, however, few other potential moderators have been explored in the literature. Identifying whether compensatory responses are greater in some children compared with others will have important implications for the design of strategies targeting specific population subgroups to decrease the potential effect of compensation on their physical activity levels.

Daily weather conditions (5,7) and daylight hours (15) have been found to influence engagement in physical activity. This may be attributable to daily fluctuations in weather conditions, which may affect spontaneous and unplanned physical activity behaviors (5), or the longer daylight hours affording children more opportunities to play outside (15). Rowlands (28) noted that an activitystat (if found to exist) is likely to be influenced by or interact with environmental factors, although few studies have specifically addressed this to date. The present study suggests that adjusting for daily meteorological conditions made little difference to the short-term compensation effects observed between days in the winter term once person-level physical activity and/or sedentary time had been accounted for. These findings lend some support to the findings of Wilkin et al. (41), who suggested that the environment had little effect on variation in physical activity, although it should be noted that this finding was based on the examination of group-level differences between children located in two geographical locations that differed in climatic conditions. It is possible that fluctuations in meteorological variables over longer periods of time may have a greater influence on compensatory changes in physical activity. However, further research is needed to examine when physical activity compensation occurs (e.g., within day, between days, and across seasons) and the influence of the environment in which an individual resides.

There are several limitations that warrant attention. It is acknowledged that this study is observational in nature and is examining compensatory changes between days. To further explore the "activitystat" hypothesis, experimental research designs that examine within-person responses to physical activity and sedentary time across different time scales (e.g., within days and between days) are required. Secondly, although the use of an objective monitor to determine changes in activity levels can be considered a strength, there is currently no consensus on the decisions made to analyze collected data (6). Consequently, variations in data management protocols (e.g., cut points and inclusion criteria) make it difficult to compare findings from different studies.

CONCLUSION

The findings from this study suggest that once individual differences in mean physical activity levels and/or sedentary time (representing a child's typical level of activity) are accounted for, children appear to compensate their activity levels between days. Additional adjustment for meteorological variables did not change the observed compensation effects. Further research is needed to develop a greater understanding of apparent compensatory changes in children's physical activity and sedentary time and to examine additional factors (e.g., physical education and sport participation opportunities) that may influence and moderate these compensatory responses.

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