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Children and adolescents do not compensate for physical activity but do compensate for sedentary behavior

Introduction

Sufficient physical activity engagement is crucial for children's physical, mental, cognitive, and social health (Biddle, Ciaccioni, Thomas, & Vergeer, 2019; Chaput et al., 2020). In contrast, engagement in sedentary behavior has been associated with negative physical and mental health outcomes (Nigg et al., 2020, Chaput et al., 2020). Thus, the World Health Organization recommends that children and adolescents engage in a minimum of 60 min of moderate-to-vigorous physical activity (MVPA) per day on average while sedentary behavior should be reduced (WHO, 2020). However, based on self-report data, globally and in Germany, 81% and 83.7% of children and adolescents do not meet

the physical activity guidelines (Guthold, Stevens, Riley, & Bull, 2020) while they spend between 4–12 h per day sedentary (Pate, Mitchell, Byun, & Dowda, 2011). When assessed via accelerometry, similar results were obtained for meeting the physical activity guidelines, while it showed that children spent on average about 5 h per day sedentary, which increased to 7.5 h during adolescence, with large variation across countries (Steene-Johannessen et al., 2020).

The low compliance rates for meeting the physical activity guidelines whilst having high levels of sedentary behavior, especially during adolescence, urge for interventions. However, to date, physical activity and sedentary behavior interventions' effects are at best moderate, but mostly small to negligible (Biddle, Petrolini, & Pearson, 2014; He et al., 2021; Metcalf, Henley, & Wilkin, 2012; Nguyen et al., 2020; Nooijen, Galanti, Engström, Möller, & Forsell, 2017). One reason for this may be that children and adolescents increase physical activity and decrease sedentary behavior in the targeted domain of the intervention, but that they compensate for the increase or decrease at another time. This potential mechanism is suggested by the Activity-Stat hypothesis (Wilkin, 2011). Based on homoeostatic principles, the ActivityStat hypothesis assumes that individuals have an innate activity center that regulates the amount of physical activity to a set point via a biological feedback loop, with in-

dividuals striving to keep a stable level of physical activity over time (Wilkin, 2011). Practically speaking, this means if physical activity increases at one time, individuals are expected to compensate with less physical activity at other times (Gomersall, Rowlands, English, Maher, & Olds, 2013). However, only a few studies investigated the ActivityStat hypothesis on a day-to-day basis in children and adolescents, with mixed findings. Ridgers and colleagues investigated the ActivityStat hypothesis in two observational studies with children between 8 and 11 years. They found that children compensated for MVPA and steps on any given day with less MVPA and steps the next day (Ridgers, Timperio, Cerin, & Salmon, 2014, 2015), thus supporting the ActivityStat hypothesis. This contrasts with findings of a study with 8th grade adolescent girls which found that more MVPA on one day was related to more MVPA the next day (Baggett et al., 2010).

Sedentary behavior has been even less investigated, with one study showing that sedentary behavior and sitting on any given day were unrelated to sedentary behavior the next day (Ridgers et al., 2015), while another study showed that sedentary behavior on any given day was associated with less sedentary behavior the next day (Ridgers et al., 2014).

In addition, previous studies suggest that health behaviors are related to each other via transfer and compensa-

tion mechanisms (Lippke, 2014). This means that people display or neglect one health behavior as a result of engagement in another health behavior. Behavioral transfer means that engaging in one health behavior (e.g., being physically active) leads to less engagement in an unhealthy behavior (e.g., less sedentary behavior), while behavioral compensation refers to engagement in a healthy behavior (e.g., physical activity) as a result of a prior or planned future engagement in an unhealthy behavior (e.g., sedentary behavior) (Lippke, 2014). Regarding physical activity, behavioral transfer and compensation have mostly been investigated in terms of eating behaviors and mostly in adults (Nigg, Amrein, Rackow, Scholz, & Inauen, 2021; Petersen, Prichard, Kemps, & Tiggemann, 2019), while research in children focusing on activity behavior is scarce.

Although physical activity and sedentary behavior are both energy-expenditure-related behaviors relevant to the ActivityStat hypothesis, we consider them as distinct health behaviors that are independent of each other based on the consensus of the Sedentary Behavior Research Network (Tremblay et al., 2017) and previous research (Thorp, Owen, Neuhaus, & Dunstan, 2011). In addition, empirical evidence of a meta-analysis supports that physical activity and sedentary behavior are only weakly related to each other (r = −0.11; Pearson, Braithwaite, Biddle, van Sluijs, & Atkin, 2014). However, the studies included in the meta-analysis were mainly based on self-reported proxy measures of physical activity and sedentary behavior, which is prone to recall bias (Nigg et al., 2020), and study designs were mostly cross-sectional. Especially the latter one is a major limitation when investigating behavioral transfer and compensation across behaviors within children and adolescents over time: In cross-sectional studies, the data obtained for behavior at one time is assumed to be stable and time-invariant (Hoffman, 2015), which then can only be used to investigate between-person differences. However, health behaviors are often not stable within a person. Using ambulatory assessment

and intensive longitudinal methods may be one way to overcome this limitation by allowing multiple assessments within individual's real-life, thus, minimizing recall-bias, maximizing ecological validity, and capturing health behavior's variability both within and between individuals (Bolger & Laurenceau, 2013; Reichert et al., 2020). Especially dynamic within-person processes are of interest as they display individuals' variations in health behaviors over time. For example, a child may engage in an hour of MVPA on one day, in 15 min the next day, in no activity on the third day, and so on. It is essential to distinguish within- from between-person processes as the two processes do not necessarily show the same associations (Hoffman, 2015). In addition, intensive longitudinal methods consider fixed and random effects. While fixed effects refer to the model of the means, describing the association between a predictor and an outcome for a typical individual, random effects consider that the association between a predictor and an outcome may be different for each individual (Bolger & Laurenceau, 2013).

Regarding the within-person association between physical activity and sedentary behavior, there are only a few studies that investigated the relationships in children's and adolescent's real-life using ambulatory assessment and intensive longitudinal data within- and between days, with mixed findings. Two studies with 8- to 11-year-old children supported that increased physical activity was compensated with more sedentary behavior within the same day (Ridgers et al., 2015) and the next day (Ridgers et al., 2014), while another study with 8th grade adolescent girls showed a transfer effect on less inactivity the next day (Baggett et al., 2010). For sedentary behavior, one study showed that more sedentary behavior on any given day was transferred to less MVPA within the same day in adolescent girls (Baggett et al., 2010). In 8- to 11-year-old children, more sedentary behavior on any given day was unrelated to MVPA the next day in one study (Ridgers et al., 2014), while another study showed that more sitting was transferred to fewer steps the next day (Ridgers et al., 2015).

Summarized, there is a lack of studies investigating within-person associations within physical activity and sedentary behavior as well as between physical activity and sedentary behavior within and between days. Studies showed mixed results and focused on specific samples. Thus, the purpose of this study is to investigate the ActivityStat hypothesis as well as behavioral transfer and compensation between MVPA and sedentary behavior within and between days using data of a national cohort study in Germany with children and adolescents between 6 and 17 years and device-based assessment of physical activity and sedentary behavior. We hypothesize that

1. More MVPA on one day is associated with less *next-day* MVPA (H1).
2. More sedentary behavior on one day is related to more *next-day* MVPA (H2).
3. More sedentary behavior is negatively related to *same-day* MVPA (H3).
4. More sedentary behavior on one day is associated with less *next-day* sedentary behavior (H4).
5. More MVPA on one day is related to more *next-day* sedentary behavior (H5).
6. More MVPA is negatively related to *same-day* sedentary behavior (H6).

Methods

Procedures and participants

We obtained data from the German national Motorik-Modul (MoMo) study (Woll et al., 2021), which is an in-depth study with a focus on physical activity and physical fitness within the Robert Koch Institute's German Health Interview and Examination Survey for Children and Adolescents (KiGGS; Kurth et al., 2008). Study participants were selected based on a multistage sampling approach with two evaluation levels (Kamtsiuris et al., 2007): First, a systematic sample of 167 primary sampling units was selected from an inventory of German communities stratified according to the classification system according to the level of urbanization and geographic distribution. Second, an age-stratified sample of randomly selected children

and adolescents was drawn based on the official registers of local residents. Participants or their custodians were informed about the study's aims, content, and data protection, and gave written consent. Children and parents were free in their decision to participate in the study. Parents and children were invited to examination rooms within proximity to their homes for data collection. The study was conducted according to the Declaration of Helsinki. Ethics approval was provided by the Karlsruhe Institute of Technology.

Measures

Physical activity and sedentary behavior. We asked study participants aged 6 to 17 years to wear an accelerometer (ActiGraph GT3x+ or ActiGraph wGT3X-BT, Pensacola, FL, USA) for 7 consecutive days. More detailed information about accelerometer use in the MoMo study is available elsewhere (Burchartz et al., 2020). Participants were instructed to place the belt-attached accelerometer around the hip on the right side and to wear it during waking hours. Data were sampled using a frequency of 30 Hz. Downloaded data were converted into 1 s epochs and reintegrated into 15 s epochs. To determine MVPA and sedentary behavior, we applied two cut-off point systems that are commonly used for the specific age groups 6 to 10 years (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008) and 11 to 17 years (Romanzini, Petroski, Ohara, Dourado, & Reichert, 2014). Based on the Choi algorithm (Choi, Liu, Matthews, & Buchowski, 2011), non-wear time was defined as 90 min without consecutive zero/nonzero counts. We chose the 90 min non-wear period due to the stability when using different intensity determination algorithms for different age groups and as a more conservative approach would have excluded the majority of children with overweight or obesity (Toftager et al., 2013). For our analysis, we considered days with at least 10 h of accelerometer wear-time as valid (Migueles et al., 2017).

Sociodemographic variables and weight status. Variables assessed included gender (male/female), weight status, and socioeconomic status. Trained staff assessed height and weight. Based on this information, body mass index (BMI) categories were established using the cut-off points of the International Obesity Task Force (Cole, Bellizzi, Flegal, & Dietz, 2000; Cole, Flegal, Nicholls, & Jackson, 2007). The socioeconomic status is a multidimensional construct based on information of both parents regarding education, occupational status, and net income. For children with separated parents, the socioeconomic status of the parent they live with was used (Lampert, Müters, Stolzenberg, & Kroll, 2014). From the information obtained, a score was created with the first quintile of the score being categorized as low socioeconomic status, the second to the fourth quintile being categorized as medium socioeconomic status, and the fifth quintile being categorized as high socioeconomic status (Lampert et al., 2014).

Statistical analysis

A priori, we set the significance level to $p < 0.05$. As visual inspection of our data did not reveal substantial deviations from a normal distribution, we analyzed our data using multilevel model analysis (Bolger & Laurenceau, 2013) in SPSS (version 27). We calculated two-level models with daily assessment of MVPA and sedentary behavior (level 1) nested within participants (level 2). First, we ran Pearson correlation analysis between our model predictors to detect any multicollinearity problems, considering correlations ≥ 0.70 as multicollinear (Tabachnick & Fidell, 2013). Next, we calculated the intraclass correlation coefficient by calculating a null model for MVPA and sedentary behavior to obtain information about the overall variance that is due to between-person effects (Singer, Willett, & Willett, 2003). To distinguish between within- and between-person effects for MVPA and sedentary behavior, we performed centering. For within-person effects, we centered MVPA and sedentary behavior on the participant's mean throughout the study week by subtracting the par-

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Abstract

Little is known about behavioral transfer and compensation within and between moderate-to-vigorous physical activity (MVPA) and sedentary behavior. Thus, taking a within-person perspective, this study investigated across 1 week whether (a) children and adolescents compensate for increased MVPA and sedentary behavior with less of the respective behavior the next day and (b) transfer and compensation occur between these behaviors within 1 day and across 2 days. We obtained data from 2676 participants (6–17 years) of the national Motorik-Modul (MoMo) study in Germany. Participants wore an ActiGraph accelerometer (Pensacola, FL, USA) for 7 days. We analyzed within- and between-day associations using hierarchical linear modeling. If youth engaged in 2 h more sedentary behavior than typical on any given day, they engaged in 37.20 min less MVPA the same day (B = −0.31, $p < 0.001$) as well as in 4.80 min more MVPA (B = 0.04, $p < 0.001$) and 7.20 min less sedentary behavior (B = −0.06, $p < 0.001$) the next day. If youth engaged in 1 h more MVPA than typical on any given day, they engaged in 97.80 min less sedentary behavior the same day (B = −1.63, $p < 0.001$) and in 5.40 min less sedentary behavior the next day (B = −0.09, $p < 0.001$). No association with next-day MVPA was observed. Our results indicate that children do not compensate for enhanced MVPA but transfer to less sedentary behavior, while more sedentary behavior is compensated with less sedentary behavior and more MVPA the next day. This provides essential information for the design of intervention studies to tackle physical inactivity and sedentary behavior.

Keywords

ActivityStat · Compensation · Transfer · Multiple health behavior change · Youth

Table 1 Study sample characteristics (*N* = 2676)

Age in years (M, SD)	12.67 (3.27)
Girls (%)	52.1
Body mass index (%)	
Underweight	9.0
Normal weight	73.1
Overweight	13.8
Obese	4.0
Parental education (%)	
Low	7.8
Medium	64.5
High	27.6
Sedentary behavior, minutes/day (M, SD)	566.26 (121.82)
MVPA, minutes/day (M, SD)	51.85 (24.34)
Accelerometer wear-time, minutes/day (M, SD)	820.63 (73.53)

M mean, *SD* standard deviation, *MVPA* moderate-to-vigorous physical activity

ticipant's individual mean across the study week from the daily value. For between-person effects, we calculated the participant's mean throughout the study week and performed grand-mean centering by subtracting the mean of all participants from each person's study week mean. To investigate associations prospective associations between one and the next day, we time-lagged MVPA and sedentary behavior by one day.

To test our hypotheses, we set up multilevel models. We evaluated the model fit based on Aikeke's Information Criterion and Schwarz's Bayesian Criterion, with lower values indicating a better model fit (Hoffman, 2015). In model 1, we considered engagement in MVPA (minutes/day) as the linear function of MVPA the previous day (H1), sedentary behavior the previous day (H2), and sedentary behavior the same day (H3). In model 2, we considered engagement in sedentary behavior as the linear function of sedentary behavior the previous day (H4), MVPA the previous day (H5), and MVPA the same day (H6). Following established procedures, we included random effects the intercept and each predictor above but only kept them if they were significant (Bolger & Laurenceau, 2013; Reichert et al., 2017). Based on pre-

vious findings (Kontostoli et al., 2021; Lämmle, Worth, & Bos, 2012; Mielke, Brown, Nunes, Silva, & Hallal, 2017; Mitchell et al., 2013), we included age (centered on the sample's mean), gender (reference category: males), BMI (reference category: normal weight), and socioeconomic status (reference category: medium socioeconomic status) in our model. In addition, we included the variable "week part" that distinguished between weekdays (Monday to Friday; reference category) and weekend days (Saturday and Sunday) due to the assumption that weekend days and weekdays are structurally different regarding the children's schedules (Brazendale et al., 2017). Furthermore, to consider time effects (Bolger & Laurenceau, 2013), we considered time via the number of the study day (range 0–6). In addition, we included accelerometer wear-time both on the same day as well as time-lagged for one day centered on the sample's mean into our model. The equations for model 1 and model 2 can be found in *supplement S1*. To explore potential differences based on individual characteristics and time, we calculated interactions between gender, age, BMI, week part, and our predictors of interest, respectively. To explore the robustness of our results, we excluded outliers ±3 SD around the mean (Howell, 1998).

Results

Descriptive information

In total, 4569 youth between 6 and 17 years participated. A total of 2734 participants agreed to wear an accelerometer. Of those, 2676 participants had a least one day with ≥10 h of accelerometer wear time. A detailed description of our study sample can be found in ◻ **Table 1**. We obtained a total of 15,420 valid accelerometer days with an average of 5.76 (SD = 1.48) valid accelerometer days per participant. The intraclass correlation coefficient was 0.41 for MVPA and 0.61 for sedentary behavior, which means that 41% of the variance in MVPA and 61% of the variance in sedentary behavior is explained between-person. Hence, 59%

and 39% of the variability occur within-person, respectively.

Hypothesis testing

As the model fit improved when we included sociodemographic and individual predictors, we present the fully adjusted model in ◻ **Table 2**. For estimates of the sociodemographic and individual predictors, see *supplement Table S1*.

Several behavioral relationships within and between days emerged. For MVPA as the outcome, we did not include sedentary behavior as a between-person predictor due to a strong correlation with age (r = 0.78, p < 0.001), causing multicollinearity problems. While MVPA the previous day was not associated with MVPA the next day (B = 0.01, p = 0.485), thus rejecting H1, higher sedentary behavior on the previous day was associated with more MVPA the next day (B = 0.04, p < 0.001), thus confirming H2. In addition, more sedentary behavior was associated with less MVPA the same day (B = −0.31, p < 0.001), thus confirming H3. Demonstrating this with an example: if a child engaged in 2 h more-than-usual sedentary behavior on any given day (which, for example, could be the duration of watching a movie while sitting on the couch), they engaged in 4.80 min more MVPA the next day and engaged in 37.20 min less MVPA the same day (◻ **Fig. 1**).

Interaction analysis revealed that gender moderated the relationship between same-day sedentary behavior and MVPA (B = 0.03, p < 0.001), showing stronger MVPA decreases in boys.

Age also moderated the relationship between same-day sedentary behavior and MVPA (B = 0.01, p < 0.001), showing stronger MVPA decreases in younger compared to older children. Age also moderated the relationship between previous-day sedentary behavior and MVPA (B = 0.002, p = 0.006), showing stronger MVPA increases in older compared to younger children. The association between previous-day sedentary behavior and MVPA was also moderated by BMI, but these results were not obtained when outliers were excluded. However, when outliers were not considered, the as-

Table 2 Multilevel models predicting MVPA and sedentary behavior

	Fixed effects				Random effects			
	B	SE	t (df)	P	Variance estimate	SE	Wald Z	P
Outcome: MVPA								
Intercept	59.73	0.94	63.68 (2612)	< 0.001	529.33	19.54	27.08	< 0.001
SB within-person same day	−0.31	0.004	−86.91 (4209)	< 0.001	0.002	0.000	6.48	< 0.001
SB within-person previous day	0.04	0.005	9.44 (7159)	< 0.001	0.001	0.000	3.20	0.001
MVPA within-person previous day	0.01	0.01	0.70 (3581)	0.485	0.01	0.002	3.49	< 0.001
Outcome: Sedentary behavior								
Intercept	568.63	1.61	354.24 (3673)	< 0.001	1274.61	45.46	28.04	< 0.001
MVPA within-person same day	−1.63	0.02	−80.63 (1504)	< 0.001	0.24	0.02	10.18	< 0.001
MVPA within-person previous day	−0.09	0.02	−4.62 (10,530)	< 0.001	–	–	–	–
SB within-person previous day	−0.06	0.01	−7.02 (10,871)	< 0.001	–	–	–	–
MVPA between-person	−1.72	0.04	−44.02 (2465)	< 0.001	–	–	–	–

All models were controlled for time, age, socioeconomic status, body-mass-index, weekday/weekend day, time, and accelerometer wear-time the same and previous day. Age and accelerometer wear-time were grand-mean centered. Socioeconomic status is centered on the medium socioeconomic status, BMI on the normal weight category, gender on males

SB sedentary behavior, *MVPA* moderate-to-vigorous physical activity

sociation between same-day sedentary behavior and MVPA was moderated by week part, showing slightly stronger MVPA decreases on weekdays compared to weekend days (*supplement Table S2*).

For sedentary behavior as the outcome, more sedentary behavior the previous day was associated with less sedentary behavior the next day (B = −0.06, $p < 0.001$), thus confirming H4. More MVPA the previous day was associated with less sedentary behavior the next day (B = −0.09, $p < 0.001$), thus rejecting H5, while more MVPA on any given day was related to less sedentary behavior the same day (B = −1.63, $p < 0.001$), thus confirming H6. In addition, MVPA was negatively related to sedentary behavior on the between-person level (B = −1.72, $p < 0.001$), which means that children who on average engage in more MVPA engage in less sedentary behavior (◘ Table 2). Another example to illustrate this: if a child engaged in 2 h more sedentary behavior than usual on one day, they engaged in 7.20 min less sedentary behavior the next day. If a child engaged in 1 h more MVPA than typical on one day, which for example may be the case when attending a sports club session, the engaged in 5.40 min less sedentary behavior the next day and in 97.80 min less sedentary behavior the same day. On the between-person level, engagement in an average of 60 min MVPA daily (the minimum recommendation of the

World Health Organization) is related to 14.03 min less sedentary behavior daily (◘ Fig. 1).

Interaction analysis revealed that gender moderated the relationship between same-day MVPA and sedentary behavior, showing stronger sedentary behavior decreases in girls. However, this interaction did not remain significant when outliers were excluded. Also, age moderated the relationship between same-day MVPA and sedentary behavior (B = 0.01, $p = 0.026$), showing stronger sedentary behavior decreases in younger children compared to older children. In addition, week part moderated the relationship between same-day MVPA (B = −0.13, $p = 0.001$) and previous-day MVPA (B = −0.10, $p = 0.009$) and sedentary behavior, respectively, showing stronger sedentary behavior decreases on weekend days (Saturday and Sunday) compared to weekdays. No interaction was observed for BMI. All interaction results can be found in *supplement Table S3*.

All other results remained stable when outliers were excluded.

Discussion

This study provides unique insights into behavioral transfer and compensation within and across MVPA and sedentary behavior in a cohort with over 2500 children and adolescents between 6 and

17 years. Summarized, more MVPA on one day was unrelated to MVPA the next day, while engagement in more sedentary behavior on one day was related to less sedentary behavior the next day. Cross-behavioral relationships were also observed: children engaging in more sedentary behavior on one day engaged in less MVPA the same day, but compensated with more MVPA the next day.

In detail, between one and the next day, our study showed support for the ActivityStat hypothesis for sedentary behavior, but not for MVPA. For sedentary behavior, our results are supported by one previous study's findings (Ridgers et al., 2014). Regarding MVPA, our study did not support an association between one and the next day. These findings contribute to the ambiguity around associations between MVPA across 2 days, with one experimental study supporting our study's findings (Ridgers, Lamb, Timperio, Brown, & Salmon, 2018b), while two other observational studies with 8- to 11-year-old children supported compensation between 2 days (Ridgers et al., 2018a; Ridgers et al., 2014), and another study with adolescent girls actually supports transfer effects (Baggett et al., 2010). The differences between the other studies' findings and our findings may be the result of different samples. For example, Ridgers et al. (2018a) reported that their participants were all from schools that
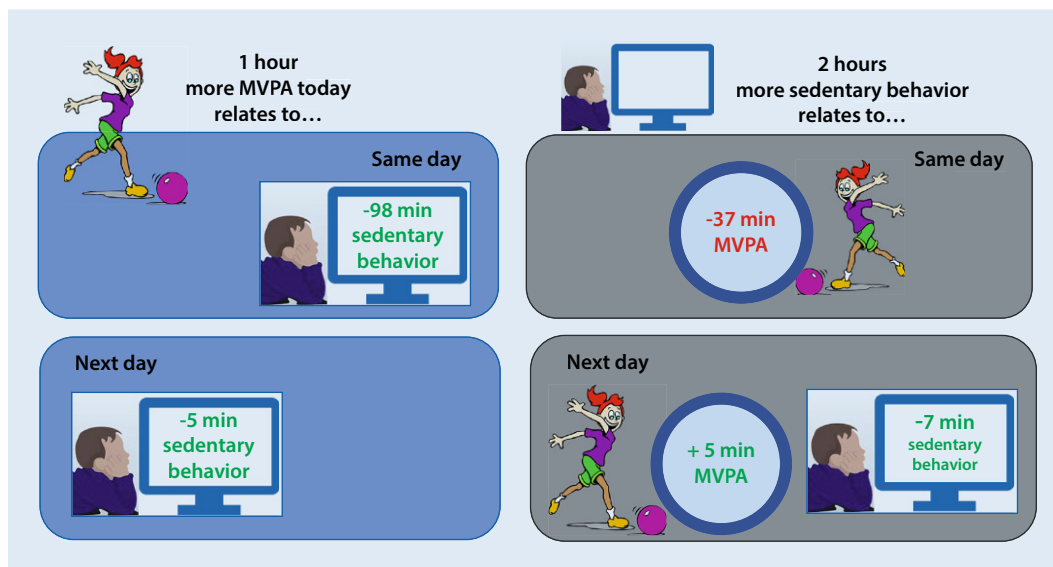
Fig. 1 ◄ Associations between moderate-to-vigorous physical activity and sedentary behavior within a day and across 2 days. *MVPA* moderate-to-vigorous physical activity

were in areas with a high socioeconomic status and their age range was limited to 8–11 years. The distinct associations for MVPA and sedentary behavior between two days support that compensation and transfer are different for the two behaviors. In our example, we demonstrated that two more hours sedentary behavior, such as watching a movie while sitting on the couch, is related to a 7-minute decrease in sedentary behavior the next day.

Regarding cross-behavioral relationships, our findings indicate that more sedentary behavior on any given day is transferred to less same-day MVPA but compensated with more next-day MVPA. The same-day findings are in line with results of previous studies in adolescents, showing that more inactivity on one day relates to lower MVPA the same day (Baggett et al., 2010) and that sedentariness is not compensated with more activity at other time points during the day (Jakubec, Frömel, Chmelík, & Groffik, 2020). Theoretically, this is supported by the displacement hypothesis suggesting that sedentary activities, such as drawing or puzzling while being seated, displace physical activity (Mutz, Roberts, & Vuuren, 1993). Regarding the next day, our study supports the hypothesized compensation mechanism, with children compensating for more sedentary behavior on any given day with more next-day MVPA. This contradicts previous find-

ings in children and adolescents that either showed no association between the two behaviors for that time period or indicated that more sedentary behavior was transferred to less physical activity (Baggett et al., 2010; Ridgers et al., 2018a; Ridgers et al., 2018b). In our example, we demonstrated that 2 h of more sedentary behavior, such as watching a movie while sitting on the couch, is associated with a 5-minute increase in next-day MVPA. Although this may seem negligible, even small positive changes in MVPA may yield health benefits, such as decreases in body fat (Stevens et al., 2007). In addition, a 4-minute increase in MVPA has been found to be the average effect of physical activity interventions (Metcalf et al., 2012).

Furthermore, our results show that more MVPA is associated with less same-day and next-day sedentary behavior, thus indicating behavioral transfer. The results for both within and between days are supported by one study with adolescent girls (Baggett et al., 2010); however, younger children (8–11 years) compensated for MVPA with more sedentary behavior the next day (Ridgers et al., 2018a; Ridgers et al., 2014). Again, those differences may be explained by the rather different samples used in our study compared to the other two studies. Our results may indicate that MVPA could serve as a gateway health behavior (Lippke, 2014), which means that

changes in physical activity may have a positive influence on other health (risk) behaviors, such as sedentary behavior.

Several interactions between our predictors of interest, participants' characteristics, and week part emerged. Although the interactions were statistically significant, we are careful in the interpretation as visual plotting revealed that those interactions play a minor role in our data and thus may be a result of our large sample. Plotting the data showed that higher-than-usual sedentary behavior was associated with a slightly stronger MVPA decrease in boys than in girls, while more-than-usual MVPA within the same day translated to slightly less sedentary behavior in girls compared to boys. A reason for this could be that girls may be more health-literate than boys (Fleary, Joseph, & Pappagianopoulos, 2018) and thus may try to mitigate the decline in MVPA. In addition, higher-than-usual sedentary behavior was related to stronger same-day MVPA decreases in younger children compared to older adolescents, while compensation with next-day MVPA was stronger in older adolescents. A reason may be that older adolescents are more aware about their sedentary behavior compared to younger children and thus try to counteract with MVPA. Furthermore, our analysis showed that more-than-usual sedentary behavior was related to a slightly weaker MVPA-decrease on

the weekend compared to weekdays. In addition, more-than-usual MVPA both on the same and the previous day was related to slightly stronger decreases in sedentary behavior. A possible explanation could be that there is more time available on weekend days, thus allowing more engagement in MVPA.

To our best knowledge, this is one of the first studies that investigated within- and between-day behavioral transfer and compensation using intensive longitudinal data and device-based physical activity assessment in a large cohort of children and adolescents across a broad pediatric age range. As there are only a few previous studies that investigated those associations on a within-person level in a limited age range of children and adolescents, this study adds by providing crucial information about possible behavioral transfer and compensation within and across MVPA and sedentary behavior that can be useful for designing physical activity and sedentary behavior interventions. However, our study is not free from limitations. Due to the observational study design, causal inference cannot be assumed. In addition, the participants wore the accelerometers for one week, and it is unclear how representative the behavioral patterns obtained during this week reflect the typical behavior of the participant. However, due to the large number of participants and the fact that the survey was conducted over a period of two and a half years and took into account not only all seasons but also vacations, the errors of an atypical week are assumed to be very small. Finally, we did not consider MVPA and sedentary behavior domains, which may have affected our associations.

These limitations notwithstanding, several future research implications arise from our study. Our analyses revealed significant random effects for all associations of interests for MVPA as the outcome. Practically speaking, this means while some children and adolescents compensate for more sedentary behavior on any given day with MVPA the next day, others may not or even transfer it to less MVPA the next day. Thus, it is important to investigate across which domains compensation

and transfer occur. While we hitherto referred to physical activity in sports clubs and sedentary behavior related to movie watching to exemplify our data, other domains, such as active transport or outdoor play for physical activity and reading, drawing, or puzzling while being seated for sedentary behavior, are highly relevant and thus should be further investigated regarding transfer and compensation mechanisms. Furthermore, our study's hypotheses are among others based on homeostatic ActivityStat principles. While a biological explanation may be plausible, it may also be the case that structural reasons are responsible for the observed associations, for example, having lots of homework on one day but not on the next day, which may translate to less sedentary behavior on the next day. Thus, future research should investigate the underlying mechanisms to allow the design of interventions based on those mechanisms. In addition, while some studies investigated within- and between-day associations, it is unclear which time frame is relevant to explore behavioral transfer and compensation (Gomersall et al., 2013). For the ActivityStat hypothesis, it has been suggested that longer time frames over several weeks or even months are important to assess those mechanisms; however, studies with repeated assessment over longer time periods in children, especially using device-based assessment, are lacking (Gomersall et al., 2013). Finally, while some experimental studies investigated behavioral compensation and transfer (Paravidino, Mediano, & Sichieri, 2017; Ridgers et al., 2018b), this was limited to one day of additional/restricted MVPA or sedentary behavior, which may be too little to translate into behavioral transfer and compensation within and across behaviors. Thus, for causal inference, intervention studies with a longer duration are required.

Practically speaking, our results indicate that more MVPA in children and adolescents has the potential to decrease sedentary behavior both on the same and the next day. Hence, opportunities for engagement in MVPA for children and adolescents, for example through ac-

tive play opportunities during recess, active transport routes, or participation in guided sports activities, should be promoted. As we observed that more sedentary behavior on one day relates to less MVPA on the same day, practitioners and families should counteract heightened sedentary periods and create opportunities for MVPA throughout the day, for example via interrupting sedentary behavior repeatedly with intense "exercise snacks" that are time-efficient and thus may be easily integrated during sedentary periods (Islam, Gibala, & Little, 2022), e.g., while sitting in the classroom, doing homework, or watching a movie.

Conclusions

Higher-than-usual sedentary behavior on any given day is compensated with less sedentary behavior and more moderate-to-vigorous physical activity (MVPA) the next day but transferred to less MVPA within the same day. These results are partially supported by previous research with children and adolescents (Baggett et al., 2010; Jakubec et al., 2020; Ridgers et al., 2014). More-than-usual MVPA is unrelated to the next day's MVPA and transferred to less sedentary behavior on the same and the next day, with previous studies' findings also partially supporting our results (Baggett et al., 2010; Ridgers et al., 2018b). This provides essential information for the design of intervention studies that tackle physical inactivity, sedentary behavior, or both behaviors.

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Declarations

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