Compensation or displacement of physical activity in children and adolescents—A systematic review of empirical studies

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Abstract

Background: Regular physical activity during childhood and adolescence is associated with health benefits. Consequently, numerous health promotion programs for children and adolescents emphasize the enhancement of physical activity. However, the ActivityStat hypothesis states that increases in physical activity in one domain are compensated for by decreasing physical activity in another domain. Currently, little is known about how physical activity varies in children and adolescents within intervals of one and multiple days.

Objectives: This systematic review provides an overview of studies that analyze changes in (overall) physical activity, which are assessed with objective measurements, or compensatory mechanisms caused by increases or decreases in physical activity in a specific domain in children and adolescents.

Methods: A systematic search of electronic databases (PubMed, Scopus, Web of Science, SportDiscus) was performed with a priori defined inclusion criteria. Two independent researchers screened the literature and identified and rated the methodological quality of the studies.

Results: A total of 77 peer-reviewed articles were included that analyze compensatory mechanisms with multiple methodological approaches. Of 40,829 participants, 16,265 indicated compensation associated with physical activity. Subgroup analyses separated by study design, participants, measurement instrument, physical activity context, and intervention duration also showed mixed results toward indication of compensation. Quality assessment of the included studies revealed high quality (mean = 0.866).

Conclusion: This review provides inconclusive results about compensation in relation to physical activity. A trend toward increased compensation in interventional studies and in interventions of longer duration can be observed.

1 Background

1.1 Health benefits of physical activity

Regular physical activity (PA) during childhood and adolescence is associated with numerous health benefits [1]. As a result of regular PA, physical fitness in children increases and is associated with improvements in cardiovascular [2] and cardiometabolic [1,2] health. Additionally, PA is associated with better mental health in children [3] and adolescents [4] and with a reduction of obesity risk [5-7]. Furthermore, establishing a physically active lifestyle at an early age seems to be important because PA levels at early ages (3 to 6 years) predict PA levels during adolescence and young adulthood [8]. In line with these finding, the World Health Organization (WHO) [9, 10] developed PA recommendations for children and adolescents. Briefly, it is recommended for children 3 to 4 years of age to be physically active for at least 180 minutes daily and for children 5 to 17 years of age to accumulate at least 60 minutes of moderate-to-vigorous PA (MVPA) daily [10]. However, recent analyses have demonstrated that PA levels of children and adolescents in many regions worldwide are not meeting the WHO recommendations [11-13].

1.2 Promotion of physical activity

There have been and continue to be numerous efforts to promote PA in children and adolescents, aiming at helping them develop a more active lifestyle [14-17]. Various contexts serve as a setting for PA promotion. In fact, there are several reviews that underpin the benefits of PA programs among healthy children [15, 18, 19]. Schools, for example, have been identified as an ideal setting for the promotion of PA among children and adolescents because no other institution has as much influence on children during their first two decades of life [15, 18]. Furthermore, walking is identified as an ideal option for health promotion because it is both cheap and easy to implement and no training is required [20]. However, there is little evidence regarding the magnitude of the contribution that active commuting to school might make to children's overall PA [21].

1.3 ActivityStat hypothesis

PA promotion serves as a preventive health strategy [22, 23]. To succeed the health benefits of PA, it is essential to fully understand the PA determinants. Most research has thus far focused on the psychosociological, social, and environmental issues that affect PA levels [24]. In contrast, the potential effect of intrinsic biological control on regular activity has received little attention [25]. With Rowland's "ActivityStat" hypothesis [26], the research on biological control that underpins PA and energy expenditure has gained momentum in the literature [27]. Briefly, the ActivityStat hypothesis suggests that an imposed increase or decrease in PA in one domain might induce a compensatory change in the opposite direction in another domain in order to maintain a level of PA or energy expenditure that is overall stable over time [27]. Thus, based on the ActivityStat concept, human beings maintain their total PA at a constant level by adapting various mechanisms, such as increasing or decreasing the frequency, intensity, or duration of time spent engaged in PA [28]. By such adapting mechanisms, their actual energy expenditure can either be increased or decreased so that the overall energy expenditure is stable over a certain period of time. For example, on a day when a child has physical education (PE) classes at school, the child may experience an increase in PA in the morning. However, the child may subsequently increase the time that it spends being sedentary in the afternoon, resulting in an overall PA level that is not increased for this day.

1.4 Compensatory changes for imposed physical activity in the scientific literature

A review of school-based PA programs has concluded that there is solid evidence that school-based interventions have a positive impact on the duration of PA with generally no effects on leisure time PA [15]. The review implies no substantial evidence that there is compensation being made for the PA imposed through interventions by having the PA decrease in another domain [15]. However, the studies included in that review rarely analyzed the occurrence of compensatory mechanisms. Generally, for studies with subjective PA measuring methods, potential compensation mechanisms are hardly ever identified [29]. Other research has found that school-based interventions demonstrate small or moderate effects on increasing PA within the school setting and that PA interventions result in little to no change in terms of overall PA levels as a result of compensatory mechanisms employed outside of the school setting [30-37].

A systematic review of active commuting to school and children's PA levels has revealed, in 50% of the studies included, that children who actively commute to school exhibit higher PA levels in all analyzed domains (commuting to school itself, active commuting to other destinations, recreational physical activities, organized sports, or in-school PA) [19]. However, most of the studies included in this review did not analyze the changes in overall PA due to an increase in PA in a specific context or did not perform analyses in different domains or time-spans [19]. Nevertheless, in order to obtain evidence regarding the general effectiveness of interventions on overall PA levels (which are essential for growing up healthy), a holistic approach is important—one that analyzes different domains and time periods of a day in children and adolescents (e.g., physical activities in school and outside of school) in addition to overall PA. Such analysis could provide insights into the potential compensatory mechanisms and rearrangements mentioned in the ActivityStat hypothesis.

In contrast, the ActivityStat hypothesis has been significantly less often investigated in children and adolescents in comparison to adults. A recent study has examined the compensation effect in accelerometer-measured occupational and non-occupational PA in adults. The findings reveal that adults who increase their occupational moderate-to-vigorous PA (MVPA) do not compensate for this increase by reducing their non-occupational MVPA. However, adults who perform more occupational light PA (LPA) do compensate by reducing their non-occupational LPA [38]. In another study, adults are found to compensate for acute physical exercises by decreasing their MVPA and LPA, while increasing their sedentary time in the days following physical exercise [39]. These two studies show how equivocal the findings tend to be in the context of PA and compensation, indicating a need for further investigation in order to understand the reasons and potential mechanisms behind this phenomenon.

1.5 Displacement hypothesis

The original displacement hypothesis postulates a mechanism that opposes the ActivityStat hypothesis, stating that television watching and other sedentary behaviors may displace PA [40]. Different studies have suggested that an increased amount of time spent being sedentary is the primary factor contributing to the current increase in obesity seen in adolescents [41-45]. Due to its inverse relationship, this original hypothesis can also be used to justify the displacement of inactivity with PA. However, little evidence exists that supports this assumption in children and adolescents under 18 years of age [46].

1.6 Aims of the present review

Little is known about how PA varies in children and adolescents within intervals of one and multiple days [47]. Additionally, the question arises whether and how inactive or sedentary time can be displaced by PA within a day or over a period of several days in children and adolescents. For children and adults, a systematic review by Gomersall et al. [27] has found inconclusive results with regards to the ActivityStat hypothesis. This review was limited in its scope because it exclusively considered studies that made explicit reference to *compensation*. Thus, the term c*ompensation* had to be mentioned in the title or abstract of a study in order for it to be included in this review. Overall, to the best of our knowledge, no review has yet analyzed PA compensation in children and adolescents within intervals of one and multiple days.

Consequently, this systematic review aims to provide a synthesis of studies that analyzed changes in overall PA among children and adolescents within the context of PA interventions. Specifically, the present review aims: (i) to provide an overview and analysis of studies that examined changes in (overall) PA, assessed with objective measurements, in children and adolescents and (ii) to identify whether compensatory mechanisms follow PA increases or decreases in one domain or during a time-span of the day (e.g., at school, in the morning) or in terms to the amount at a specific intensity level (e.g., light, moderate, or vigorous PA).

2 Methods

This systematic review was performed and is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Additional file 1) [48].

2.1 Eligibility criteria

Studies were deemed to be eligible if they met the following criteria: (1) PA or energy expenditure was objectively measured; (2) changes in (overall) PA or (overall) energy expenditure caused by an increase in PA in a specific domain or during a specific time-span (e.g., at school; in the morning) were investigated and statistically analyzed; (3) participants in the study were healthy children and adolescents (3 to 18 years of age or their mean age was in this range); (4) the study was published in a peer-reviewed journal in the English or German language; and (5) the article was published in the year 2000 or later.

We included interventional as well as non-interventional studies. Interventional studies offered the opportunity to obtain information about "ActivityStat" by investigating intra-individual changes in PA levels in response to an intervention stimulus. Non-interventional studies were included if they investigated PA levels of individuals during different time-spans or in different domains over a period of several days.

2.2 Search strategy

The search was performed on 31 March 2020 using the electronic databases PubMed, Scopus, Web of Science, and SportDiscus. The search strategy included using a combination of terms related to children and youth (child* OR youth* OR adolescen* OR boy* OR girl* OR student* OR pupil*), terms related to PA compensation (increas* OR decreas* OR "more activ*" OR improve* OR "less activ*" OR compensat* OR displace* OR change* OR activitystat), terms related to measurement methods ("objective* measure*" OR acceleromet* OR pedomet* OR "heart rate monitor*" OR "doubly labeled water" OR calorimet* OR "direct* observ*"), and outcome-related terms ("physical activ*" OR "energy expenditure"). Two filters were used to refine the results and to obtain the final reference sample for screening. In accordance with the set inclusion criteria, studies "published between 2000–2020" were selected. The publication type was filtered for journal articles (PubMed: "journal article"; SportDiscus: "academic journal", "peer reviewed"; Scopus: "articles"; Web of Science: "Article"). In accordance with recommendations for systematic reviews [49], we screened the reference lists and citations of included articles in order to identify additional relevant studies.

2.3 Study selection

Identified references were imported into Endnote X9, a reference management software [50]. Subsequently, the citations were imported into *Covidence,* a systematic review software [51]. Within this program, all duplicates were removed. This step was followed by a three-step study selection process, comprising (1) title-screening, (2) abstract-screening, and (3) full-text-screening for inclusion criteria by two independent reviewers (FB, trained student assistant). During each step of the screening process, all references that could not conclusively be excluded were kept for further screening in the next step. Disagreements between the two reviewers in relation to final inclusion were resolved through discussion with a third researcher (AKR).

2.4 Data extraction

The following data were extracted from each article: author(s); country; study design; sample description (number of participants, age, sex); aim/purpose of the study; measurement and instrument of measurement as well as duration of measurement; context of PA, main study results on the relationship between PA in one domain and PA in another domain/overall PA; statistical indicators for compensation.

Studies were also classified by taking into consideration different settings or contexts in which PA was measured. In relation to the main objectives of the study, six settings were defined (school-based PA, physical education, active commuting to school, daily pattern, sport clubs, and others). All included studies were allocated to one of these categories.

2.5 Quality assessment

The methodological quality of the included studies was rated by two independent reviewers (FB, trained student assistant). To assess the quality of each study, criteria for evaluating primary research articles, developed by Kmet et al. [52], were applied. We decided to use this tool because it is appropriate for a variety of different study designs. The "QualSyst" scoring system is based on existing tools and particularly relies upon the instruments developed by Cho and Bero [53] and Timmer et al. [54] for quantitative studies. A series of 14 items was used to assess quality. These items included questions related to study design, methods of participant selection, random allocation procedure, blinding, outcome measures, sample size, estimate of variance, confounding, reporting of results, and the evidence base for the conclusion. The items were scored depending on the degree to which each criterion was met ("yes" = 2, "partial" = 1, "no" = 0). If an item was not applicable to a particular study design, it was coded with "N/A" and was excluded from the calculation of the summative score. Randomization was scored only in interventional studies. The following equation was applied for estimating quality scores: 28 – (number of N/A × 2). Consequently, 28 was the maximum score that could be obtained for the 14 questions. The risk of bias was evaluated with its summary score (range 0–1), whereas higher scores indicated better methodological quality.

2.6 Synthesis of results

It was anticipated that the studies included in this systematic review would exhibit a diverse range of research methods (e.g., study design, intervention characteristics, setting, measurements, participant characteristics, outcome measures). Therefore, it was not appropriate to use meta-analysis to integrate and summarize the included studies. Instead, a narrative synthesis of results was performed. Summary tables describing the detailed characteristics of included studies and the visualization of statistical indicators, describing the probability for compensation related to these characteristics, were provided. The included studies and their findings were grouped according to study design, sample size, target group, dependent variable, geographic origin, PA context, measurement instrument, duration of intervention (if this information was provided), intervention type, and time-span in which compensation was measured. Analyses of compensatory mechanisms were performed for different categories, which seemed to be helpful for understanding compensation. In this respect, the aim was to determine which study design, target group, measurement instrument, PA context, time-span, and intervention duration, as well as type, was susceptible to compensation. A study was voted to be "supporting

compensation" if overall PA did not change with respect to different time points, or if it did not differ between intervention group(s) and control group(s), or if there was a significant increase in PA in one domain or time-span and a significant decrease in PA in another domain or time-span.

3 Results

3.1 Flow chart

A total of 5,917 potentially relevant articles (or 10,946 including duplicates) were identified through database searches and their titles and abstracts were screened. In the next step, the full texts of 95 studies were retrieved for in-depth screening. Since 20 articles were excluded due to inappropriate aims of study, statistical analysis, participants, or multiple reasons, a total of 75 articles were identified as eligible and were included in this systematic review. Two additional relevant publications were identified through backward reference tracking, yielding a total of 77 articles reporting on 74 unique studies included in this systematic review (Figure 1). The PA as Civil Skill Program was published in two studies that focused on LPA [55] and moderate PA (MPA) [56], respectively. The PHASE-Study was also reported in two separate articles. While Ridgers et al. [57] focused on the association between daily PA on two following days, Ridgers et al. [58] analyzed the correlations between the amount of sitting, standing, and stepping time within and between days in primary schoolchildren. Furthermore, two articles included in this review were part of the TEACHOUT-Study and investigated general effects of education outside the classroom [59] and effects of education outside the classroom in different domains [60].

3.2 Characteristics of included studies

A complete data extraction table for each included study can be found in Additional file 2. A synthesis of the characteristics of the included articles is presented in Table 1. The majority of included articles (N = 49; 64%) presented non-interventional studies and 36% presented interventional studies. The sample size ranged from 13 [61] to 6,916 participants [28] with the mean sample size of 532 participantsThe geographical origin of the studies was as follows: n = 40 Europe, n = 21 North/Mid America, n = 10 Australia/New Zealand, and n = 6 Asia. Most studies (76%) were published between 2011 and 2020 with the earliest being published in 2000. The main focus of 65 studies (84%) were schoolchildren, while 12 (16%) studies focused on preschoolers. There were 4 studies that targeted only girls [28, 62-64] and 2 only boys [65, 66]. Only 10 studies explicitly stated that their aim was to test compensation [28, 67-75] and, of these studies, 2 specifically mentioned the ActivityStat hypothesis [71, 74]. There were 63 studies that used accelerometry to objectively assess PA, 13 used pedometers, and 1 used a heart rate monitor. A SenseWear Armband was used in 2 studies, in addition to an accelerometer, to assess energy expenditure [74, 76]. Included studies were assigned to one of six contexts/settings: school-based PA in children and adolescents (N = 28), active commuting to school (N = 9), daily PA pattern (N = 15), physical education lessons (N = 16), organized sports (N = 5), or others (N = 4). With respect to interventional studies, the duration of the intervention varied from one week [66, 74] to two years [36, 55, 56, 77, 78]. The average duration of the interventions was 36 weeks (standard deviation (SD) = 37 weeks). Investigation of 3 intervention types found that 50% (N = 14) were educational, 29% (N = 8) were environmental, and 21% (N = 6) were multicomponent. Regardless of their study design (interventional or non-interventional), most studies (85%) examined changes in PA within a one day period.

A total of 39 of the 77 studies, representing 16,297 (40%) children and adolescents, reported statistical indicators that emphasize the probability of compensation. From these 39 studies, 5 reported inconsistent findings in relation to compensation within the sample [64, 69, 77, 79, 80]. Furthermore, some studies indicated compensation in one interventional group (higher amount of PA during intervention) but not in the other [37, 75] —in girls but not in boys [59, 67, 81, 82] or in boys but not in girls [83]. In Table 1, an overview of all studies supporting compensation (N = 39) is presented. With respect to study design, interventional studies indicated compensatory behavior in 75% of studies (representing 76% of participants; N = 6,477), whereas non-interventional studies supported compensation in only 30% of studies (representing 30% of participants; N = 9,820) [57, 58, 67, 69, 71, 76, 80-91]. Furthermore, 42% of preschoolers and 40% of schoolchildren showed indicators for compensatory behavior. Measurements conducted with a pedometer indicated compensation in 6,938 participants (72%), whereas accelerometer measurements showed indicators for compensation in 9,309 participants (30%). In relation to the PA context, school-based PA revealed compensation indicators in 5,350 participants, which corresponds to 72% of all participants in this context, followed by active commuting to school (6,095 participants; 56%). No compensation was indicated in the sport clubs context (0%). With respect to invention duration, in studies with a duration ≥ 1 year, 100 % of participants indicated compensatory behavior. Compensation was supported in all multicomponent interventions (N = 2,074 participants) and in 64% of all educational interventions (N = 2,295 participants).

3.4 Results of methodological quality assessment

For quality assessment, we applied the "QualSyst" scoring system with a scoring range of 0–1 [52]. The mean quality score of the included articles was rated as high by both raters (mean = 0.87, SD = 0.10, range 0.5–1). The methodological quality criteria and the proportion of studies fulfilling the criteria are presented in Table 2; more detailed quality assessment of each included article is presented in Additional file 3. Items 5, 6, and 7 were only scored for randomized controlled trials (RCTs).

In RCTs, the mean quality score was 0.76 (SD = 0.11) (range 0.5–0.89). In all RCTs, poor blinding of the treatment was evident for both investigators and participants. Overall, included studies revealed a high quality and only few studies exhibited a higher risk of bias [67, 68, 89, 92].

4 Discussion

The present systematic review aims to provide a synthesis of studies that have analyzed changes in overall PA, assessed using objective measurements, or compensatory behavior caused by PA increases or decreases in a specific PA domain or during the time-span of a day in children and adolescents.

A total of 77 articles were included that investigated compensation or displacement across various contexts in children and adolescents. Overall, approximately 50% of the included articles found indicators suggesting compensation and 50% refuted compensational behavior and supported displacement of inactive time with bouts of activity. Detailed analyses based on study design, target group, instruments, context, intervention duration, and measurement duration were performed, revealing differences in compensation depending on categories. The analyses showed tendencies toward compensation in school interventions (especially with durations lasting longer than 1 year) and tendencies of displacement in the context of weekly-organized participation in sport clubs.

It is hypothesized that when PA in one domain or time-span increases, PA in another domain or time-span decreases in order to maintain the PA level constant, as postulated by the ActivityStat hypothesis [27]. In the present analysis, 38 of 77 articles, including 24,532 participants, refuted the ActivityStat hypothesis and showed an increase in overall PA that resulted from imposed PA in one domain or time-span and absence of a reduction in PA in other domains or time-spans. Sustained displacement of inactivity with PA led to an overall increased PA level, as described in the displacement hypothesis. One possible explanation for these increases in overall PA could be that imposed PA stimuli serve as some kind of trigger: PA opportunities in different contexts may stimulate children and adolescents to engage more in physical activities during the entire day [67, 73, 81, 93-95].

In our review, we distinguished between interventional and non-interventional studies. A total of 21 interventional studies (N = 6,477 participants) showed indicators for compensation, whereas only 18 non-interventional studies (N = 9,820 participants) indicated compensatory behavior. This suggests that when PA of children and adolescents is promoted in an intervention, the participants tend to compensate for the additional bouts of PA within the intervention by decreasing their activity levels during other parts of the day or in other domains so that they maintain their overall PA at a stable level. On the other hand, when children increase their PA levels on their own, without participating in an intervention program (in non-interventional studies), it seems that they do not compensate for this and ultimately increase their overall PA level. This could be due to the fact that, in these cases, their PA is more likely based on intrinsic motivation that external influences. Furthermore, interventions were mostly offered and performed in (pre)school contexts. Improvements in (pre)school PA can be compensated for by less PA outside of (pre)school [36, 37, 55, 56, 59, 62, 64, 66, 77-79, 96-103]. “It is possible that school-based interventions are too focused on school setting and children and adolescents do not translate the health message on the importance of physical activity at home or in the community” [15]. For school interventions, it has been suggested that the focus should also be placed on changing parental behaviors and awareness for the sake of adopting a sustainable active lifestyle. In addition, multicomponent interventions or interventions that include schools together with families or communities are most effective in changing PA levels [15, 35]. In general, interventions are most efficient when they operate on multiple levels [104]. “According to ecological models, the most powerful interventions should (a) ensure safe, attractive, and convenient places for physical activity, (b) implement motivational and educational programs to encourage use of those places, and (c) use mass media and community organization to change social norms and culture.” [105]. Since intrapersonal, interpersonal, organizational, community, and public policy factors can influence health behaviors, they consequently counteract compensatory behavior. Despite the fact that the literature suggests that multicomponent interventions have been shown to be useful for changing PA behavior, our results contradict this assumption by the findings of compensatory behavior in all multicomponent studies [36, 37, 77, 79, 102, 103].

Analysis of interventions pointed out a wide range in terms of intervention duration. All six studies (N = 2,541 participants) in which interventions lasted for over one year supported compensation behavior in children and adolescents [36, 55, 56, 64, 77, 78]. Nevertheless, compensatory behavior in children and adolescents was also identified in interventions that had a duration between one month and one year [37, 62, 68, 75, 79, 96-98, 100, 101, 103]. A possible explanation for this finding could be that interventions that last for a shorter period of time may have no or less effect in changing the PA behavior of children and adolescents due to a lack of time needed to progress through the six stages of change, according to the trans-theoretical model [106]. This means that children and adolescents who accumulate more MVPA during an intervention might continue to be as physically active in their leisure time as they were before the intervention. The longer an intervention lasts, the greater the probability that children and adolescents would adapt their PA and become less active in their leisure time—hence, maintaining their overall PA at a stable level.

Almost all studies included in our review captured PA data using pedometers or accelerometers. Six pedometer studies (N = 6,938 children and adolescents) reported compensatory mechanism [37, 75, 79, 82, 84, 88], whereas children and adolescents (N= 9,309) showed compensatory behavior in 32 accelerometer studies [36, 55-59, 62, 64, 66-69, 71, 76-78, 80, 81, 83, 85-87, 89, 91, 96-103]. One explanation for this finding could be that pedometers only capture step counts—an index of the number of steps a person took—whereas the overall PA levels for participating individuals remained unknown. Hence, it is likely that compensation is diagnosed through a measured reduction in steps, while other shifts in PA levels (e.g., overall MVPA) remain unconsidered. Furthermore, only one study out of the 77 analyzed studies investigated energy expenditure using a heart rate monitor and indicated compensation [107].

Besides interventions in a school context, there are two other settings in which children and adolescents are physically active. Only 57% of children and adolescents who actively commute to school showed indicators for compensation [81, 83, 84, 86]. Active commuting and independent mobility

of children provide additional opportunities for spontaneous play [95] and enable other active behaviors [108, 109]. This can lead to an increase in overall PA and, therefore, supports the displacement theory.

In the PE context, only 32% of the participants indicated compensatory behavior [67, 71, 82, 88, 89, 91]. PE classes should provide an opportunity for children and adolescents to engage in PA and to develop knowledge about and attitudes toward developing an active lifestyle [110], which could lead to displacing inactivity with active behavior. Interestingly, two articles, involving 365 participants, investigated the impact of different amounts of PE per week on overall PA levels in children and adolescents. From their findings, it can be summarized that more PE per week is not necessarily effective for increasing total PA because the PA in PE classes is often compensated for by less activity outside of the school setting [71, 89]. Consequently, future studies should assess what the right amounts and intensities of PA during PE classes would be in order to avoid compensation outside of school.

Finally, our detailed analyses reveal one PA domain in which an increase of activity levels was not found to lead to compensation but, instead, to displacement: when engaging in organized sport clubs, children and adolescents do not compensate their PA levels by being less active after the training sessions [61, 63, 111-113]. Sport clubs represent a health-promoting setting and support children and adolescents in living an active lifestyle outside sport clubs [114]. Furthermore, sport programs can provide beneficial access to and resources for recreational activities [112]. Thus, participation in sport clubs serves as an additional factor for increasing overall PA and can displace sedentary behavior.

Compensatory behavior occurs after a PA increase or decrease in one domain or time-span in order to maintain a stable overall PA level. Almost all studies in this review revealed that a PA increase in one domain or time-span is followed by a PA decrease in another domain or time-span, which is negatively connoted. Nevertheless, there exists one study [82] in our review, where compensatory behavior was found to occur after a PA reduction—leading to compensation being positively connoted.

4.1 Implications

This review of compensation for PA in children and adolescents provides inconsistent results relating to compensation. Consequently, further research is needed for better understanding of compensatory mechanisms and a recommendation is made for future studies to investigate PA behavior over a period of a few days using an objective measurement method. In addition, participants should complete a questionnaire or keep a diary in order to terminate and locate their activities and to obtain information about the reasons for their PA behavior. Social support plays an important role for sufficient PA in children and adolescents. Thus, PA behavior and attitude of family and friends can influence one's own PA and determine compensatory behavior. Additional subgroup analysis, including an examination of differences in PA by gender, age, weight status, socio-economic status (SES), and ethnicity, could provide more information about compensatory behavior. Gender differences have already been seen in a few of the included studies with inconclusive results [59, 67, 81, 83]. Additionally, various SES analyses indicate different environmental, social, and educational circumstances [115, 116]. Hence, SES is an important predictor of PA in children and adolescents [115] and can influence compensatory behavior. Unfortunately, none of the included studies investigated compensatory behavior separately for different SES. It is hypothesized that children and adolescents with lower SES compensate more often than individuals with higher SES. It would also be interesting to further investigate the setpoint for "ActivityStat" or possible differences depending on age, season, or energy intake. With the help of an experimental design, future studies could investigate when this setpoint is reached and whether there are differences. Furthermore, there are currently no existing theories that deal with the timeframe for compensation. It is hypothesized that the timeframe for compensation is unlikely to be day-to-day [27]. Currently, the timeframes in the studies examined in our review are random. Finally, combined measurement of energy expenditure and PA should be used to obtain more detailed and reliable information about compensatory mechanisms.

Practical implications refer to interventional studies: besides active PA promotion, it is important to improve the awareness in children and adolescents, as well as in their parents, regarding the importance of PA as well as to enable them to be physically active at home during their leisure time. This is necessary in order to avoid compensation that occurs when PA at home and/or in the family environment is reduced after increases in PA levels take place during interventions in, for example, the school setting.

4.2 Strengths and limitations

The main strength of this review is that we exclusively included studies that objectively measured PA, including measures that directly assessed one or more PA dimension (e.g., frequency, intensity, time, type) and captured a variety of measures, such as step counts, activity minutes, and PA intensity [117]. An additional strength lies in the fact that the systematic search of relevant primary studies employed several electronic databases and a comprehensive list of search strings. Furthermore, the reference lists of all included studies were manually checked in the search for additional relevant studies. Our search strategy was broad enough to allow us to identify relevant studies as well as to include those studies that did not analyze PA compensation as their main objective. In contrast to Gomersall et al. [27], we did not only include studies that made explicit reference to compensation. Instead, we analyzed studies investigating changes in overall PA and in different domains or time segments for compensatory mechanisms. Another strength is the inclusion of a wide range of different settings in which PA plays an important role.

A limitation of this review relates to the variety of the study designs of the included studies, which made a comparison of the results difficult. Additionally, some studies only allowed between-subject analyses, which, in turn, only enabled conclusions about compensation to be obtained from

a comparison of PA levels between two groups. For better understanding of compensatory mechanisms, within-subject analyses provided stronger results. Another limitation is that there were different PA segments in the reviewed studies, which made it difficult to compare them all.

5 Conclusion

Based on Rowland's ActivityStat hypothesis [26], this systematic review provided inconclusive results regarding potential compensatory activity behavior after changes in PA levels in one domain or during a time-span in children and adolescents. Overall, 39 studies (n = 16,297 children and adolescents) that were included in this review did exhibit indicators of compensation. In summary, the synthesis of the included studies revealed a tendency for compensatory behavior in the context of interventions, especially in interventions with a long duration (< 1 year). Furthermore, children and adolescents who regularly participated in organized sports showed no indicators for compensatory behavior. In order to verify the results of the present review, further investigations are needed.

List Of Abbreviations

LPA light physical activity

MPA moderate physical activity

MVPA moderate-to-vigorous physical activity

PA physical activity

PE physical education

RCT randomized controlled trial

SD standard deviation

WHO World Health Organization

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

Data generated and/or analyzed during the current study are mainly included in the published article and its supplementary information files. Additional data (e.g., details of the screening process) are available on request from the corresponding author.

Conflict of interests/Competing interests

The authors declare that they have no conflicts of interests or competing interests.

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Author's contribution

All authors developed the concept of the study. FB drafted the manuscript, performed the review, and synthesized the findings. AKR supervised the project. AKR and FE provided edits to the manuscript. All authors read and approved the final manuscript.

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Tables

Table 1: Characteristics and voting of all included articles

Characteristics	N studies (% of all studies)	N participants (% of all participants)	N studies to support compensation	N participants to support compensation	N studies to support displacement	N participants to support displacement	All Sources	Compensation Sources
Study design								
Non-interventional studies	32,310 (79%)	49 (64%)	18 (37%)	9,820 (30%)	35 (71%)	22,490 (70%)	[28, 57, 58, 61, 63, 65, 67, 69-73, 76, 80-91, 93-95, 111-113, 118-135]	[57, 58, 67, 69, 71, 76, 80, 82-91]
Interventional studies	8,519 (21%)	28 (36%)	21 (75%)	6,477 (76%)	10 (36%)	2,042 (24%)	[36, 37, 55, 56, 59, 60, 62, 64, 66, 68, 74, 75, 77-79, 92, 96-103, 136-139]	[36, 37, 55, 56, 59, 62, 64, 66, 68, 75, 77, 78, 96-103]
Sample Size								
< 500	57 (74%)	10,980 (27%)					[36, 55-59, 61-63, 65-68, 70, 71, 73-77, 79-83, 85, 86, 89-94, 96-98, 100-102, 112, 113, 119-125, 128, 131, 133, 134, 136-139]	
> 500	20 (26%)	29,849 (73)					[28, 37, 60, 64, 69, 72, 78, 84, 87, 88, 95, 99, 103, 111, 118, 126, 127, 129, 132, 135]	
Target group								
Preschool children (3–6 years)	12 (16%)	2,188 (5%)	5 (42%)	919 (42%)	7 (58%)	38 (58%)	[68, 97, 100-102, 123, 128, 133, 134, 136-138]	[68, 97, 100-102]
School children	65	38,641	34 (52%)	15,378 (40%)	1,269 (58%)	23,263 (60%)	[28, 36,	[36, 37, 55-59,

(> 6 years)	(84%)	(95%)					37, 55-67, 69-96, 98, 99, 103, 111-113, 118-122, 124-127, 129-132, 135, 139]	62, 64, 66, 67, 69, 71, 75-91, 96, 98, 99, 103]
Dependent Variable								
Physical Activity	40,779 (99%)	76 (96%)					[28, 36, 55-89, 91-103, 111-113, 118-139]	
Energy Expenditure	333 (1%)	3 (4%)					[74, 76, 90]	
Geographic origin								
Europe	40 (52%)	16,881 (41%)					[36, 55, 56, 59-61, 63, 64, 71, 77, 78, 80, 81, 83, 85-92, 94, 95, 98-100, 111, 113, 118, 121, 123-127, 129, 130, 133, 134]	
North America	21 (27%)	14,256 (35%)					[28, 37, 62, 67-70, 72, 73, 75, 82, 96, 97, 101, 102, 119, 128, 135-138]	
Australia/New Zealand	10 (13%)	3,548 (9%)					[57, 58, 66, 74, 76, 103, 112, 122, 131, 132]	
Asia	6 (8%)	6,144 (15%)					[65, 79, 84, 93, 120, 139]	
PA measurement instrument								
Accelerometer	63 (79%)	31,150 (76%)	32 (51%)	9,309 (30%)	36 (57%)	21,841 (70%)	[28, 36, 55-89, 91-103, 111-	[36, 55-59, 62, 64, 66-69, 71, 76-78, 80, 81,

							113, 118-139]	83, 85-87, 89, 91, 96-103]
Pedometer	13 (16%)	9,629 (23%)	6 (46%)	6,938 (72%)	10 (77%)	2,691 (28%)	[37, 61, 73, 75, 79, 82, 84, 88, 92, 119-121, 132]	[37, 75, 79, 82, 84, 88]
Heart Rate Monitor	1 (1%)	50 (0.1%)	1 (100%)	50 (100%)	0	0	[90]	[90]
Context of PA measures								
School-based PA	26 (34%)	7,392 (18%)	19 (72%)	5,350 (72%)	10 (36%)	2,042 (28%)	[36, 37, 55, 56, 59, 60, 62, 64, 66, 68, 74, 75, 77-79, 92, 96, 97, 100-103, 136-139]	[36, 37, 55, 56, 59, 62, 64, 66, 68, 75, 77-79, 96, 97, 100-103]
Active commuting to school	10 (13%)	10,733 (26%)	5 (50%)	6,175 (58%)	7 (70%)	4,558 (43%)	[81, 83, 84, 86, 95, 98, 122, 129, 131, 132]	[81, 83, 84, 86, 98]
Daily PA Pattern	15 (19%)	12,499 (31%)	7 (47%)	1,677 (13%)	8 (53%)	10,822 (87%)	[28, 57, 58, 70, 72, 76, 80, 85, 87, 90, 120, 121, 123, 128, 135]	[57, 58, 76, 80, 85, 87, 90]
Physical Education	17 (22%)	5,814 (14%)	7 (41%)	2,567 (44%)	12 (75%)	3,247 (56%)	[65, 67, 71, 82, 88, 89, 91, 93, 99, 119, 124-126, 130, 133, 134]	[67, 71, 82, 88, 89, 91, 99]
Sports Club	5 (6%)	2,583 (6%)	0 (0%)	0 (0%)	5 (100%)	2,583 (100%)	[61, 63, 111-113]	
Others (Locations/Active play)	4 (5%)	1,808 (4%)	1 (25%)	528 (29%)	3 (75%)	1,280 (71%)	[69, 94, 118, 127]	[69]
Duration of Intervention								
≤ one week	2 (7%)	207 (2%)	1 (50%)	51 (25%)	1 (50%)	156 (75%)	[66, 74]	[66]
≤ one month	1 (4%)	67 (1%)	0 (0%)	0 (0%)	1 (100%)	67 (100%)	[138]	
≤ 1−2 months	6 (21%)	869 (12%)	5 (83)	573 (66%)	2 (33%)	296 (34%)	[75, 79, 92, 96, 100, 101]	[75, 79, 96, 100, 101]
≤ 3−4 months	3 (11%)	144 (2%)	3 (100%)	144 (100%)	0	0	[62, 68, 98]	[62, 68, 98]

≤ 5–6 months	6 (21%)	2,241 (38%)	3 (50%)	1,520 (68%)	4 (67%)	721 (32%)	[37, 97, 103, 136, 137, 139]	[37, 97, 103]
≤ one year	4 (14%)	2,450 (28%)	3 (75%)	1,648 (58%)	2 (50%)	802 (32%)	[59, 60, 99, 102]	[59, 99, 102]
> one year	6 (21%)	2,541 (31%)	6 (100%)	2,541 (100%)	0	0	[36, 55, 56, 64, 77, 78]	[36, 56, 64, 77, 78, 88]
Intervention type								
Educational	14 (50%)	3,593 (42%)	9 (64%)	2,295 (64%)	7 (50%)	1,145 (32%)	[59, 60, 64, 66, 74, 75, 96, 97, 100, 101, 136-138]	[59, 62, 64, 66, 96, 97, 100, 101, 103]
Environmental	8 (29%)	2,393 (28%)	6 (75%)	2,108 (88%)	2 (25%)	285 (12%)	[55, 56, 68, 78, 92, 98, 99, 139]	[55, 56, 68, 78, 98, 99]
Multicomponent	6 (21%)	2,533 (30%)	6 (100%)	2,074 (82%)	1 (17%)	459 (18%)	[36, 37, 77, 79, 102, 103]	[36, 37, 77, 79, 102, 103]
Time-span measuring compensation								
Within a day	37,198 (91%)	65 (85%)	35 (54%)	15,567 (42%)	36 (55%)	21,631 (58%)	[28, 36, 37, 55, 56, 59-62, 64-66, 68-72, 74, 75, 77-103, 111, 118, 120, 122, 123, 126-139]	[36, 37, 55, 56, 59, 62, 64, 66, 68, 69, 71, 77-91, 96-103]
Between two consecutive days	904 (2%)	4 (5%)	3 (75%)	610 (67%)	1 (25%)	294 (33%)	[57, 58, 76, 124]	[57, 58, 76]
Across several days	2,727 (7%)	8 (10%)	1 (13%)	120 (4%)	8 (100%)	2,607 (96%)	[63, 67, 73, 112, 113, 119, 121, 125]	[67]

(numbers of compensation or displacement voting are relative to respective characteristic; studies containing both compensation and displacement results were added to either category)

Table 2: Criteria for methodological quality assessment and the number (%) of studies that scored points or each criterion

		Studies fulfilling the criteria n (%)			
No.	**Item**	**Yes**	**Partial**	**No**	**N/A**
1	Question /objective is sufficiently described?	51 (66%)	26 (34%)	0	0
2	Study design is evident and appropriate?	75 (97%)	2 (3%)	0	0
3	Method of subject/comparison group selection or source of information/input variables is described and appropriate?	64 (83%)	13 (17%)	0	0
4	Subject (and comparison group, if applicable) characteristics are sufficiently described?	50 (65%)	27 (35%)	0	0
5	If interventional and random allocation was possible, was it described?	7 (9%)	9 (12%)	1 (1%)	60 (78%)
6	If interventional and blinding of investigators was possible, was it reported?	4 (5%)	1 (1%)	12 (16%)	60 (78%)
7	If interventional and blinding of subjects was possible, was it reported?	0	1 (1%)	16 (21%)	60 (78%)
8	Outcome(s) and (if applicable) exposure measure(s) is/are well defined and robust to measurement/misclassification bias? Means of assessment are reported?	66 (86%)	11 (14%)	0	0
9	Sample size is appropriate?	70 (91%)	7 (9%)	0	0
10	Analytic methods are described/justified and appropriate?	75 (97%)	2 (3%)	0	0
11	Some estimate of variance is reported for the main results?	36 (47%)	41 (53%)	0	0
12	Controlled for confounding?	44 (57%)	31 (40%)	2 (3%)	0
13	Results reported in sufficient detail?	58 (75%)	19 (25%)	0	0
14	Conclusions supported by the results?	58 (75%)	19 (25%)	0	0

Figures

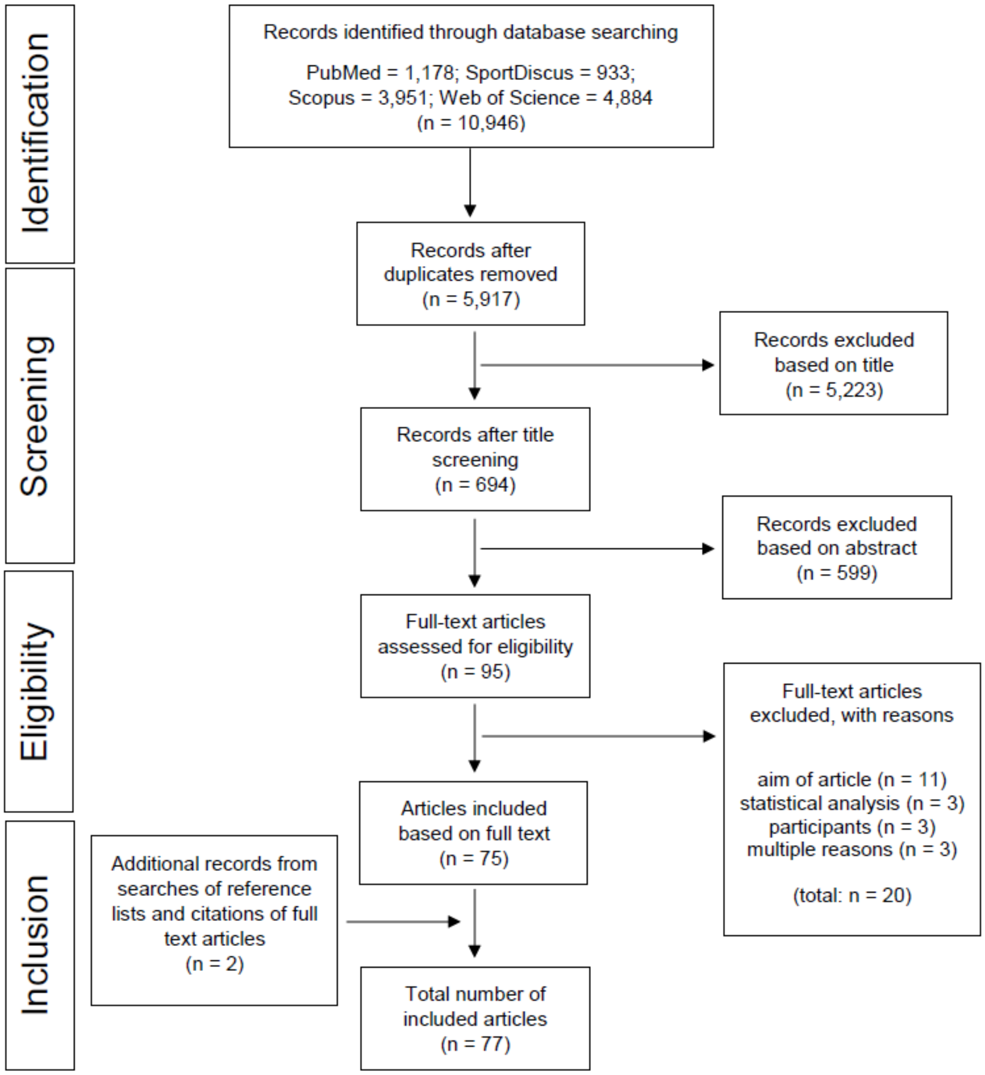

Figure 1

Flow Chart

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- additionalfile1PRISMA2009checklistReviewcompensation.pdf
- additionalfile2dataextraction.xlsx
- additionalfile3qualityassessment.xlsx