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Application of Recent Approaches in Assessment, Analysis and Explanation of Adolescent Physical Activity – Laying the Groundwork for Tailored Interventions

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List of Abbreviations

APNSEQ	Adolescent Psychological Need Support in Exercise Questionnaire
BPN	Basic psychological needs
BPNSFS	Basic Psychological Need Satisfaction and Frustration Scale
BREQ-2	Behavioural Regulation of Exercise Questionnaire 2
EMA	Ecological momentary assessment
ENERGY	European Energy Balance Research to Prevent Excessive Weight Gain Among Youth
GINI	German Infant Nutrition Intervention Programme Study
HELENA	Healthy Lifestyle in Europe by Nutrition in Adolescence
Hz	Hertz
IDEFICS	Identification and Prevention of Dietary- and Lifestyle-Induced Health Effects in Children and Infants Study
KiGGS	German National Health Interview and Examination Survey for Children and Adolescents
MATLAB	Matrix laboratory
MCFA	Multi-level confirmatory factor analysis
MVPA	Moderate-to-vigorous physical activity
PA	Physical activity
PE	Physical education
SB	Sedentary behaviour
SDT	Self-determination theory
SES	Socioeconomic status
SOM	Self-organizing maps
SPSS	Statistical Product and Service Solutions
VM	Vector magnitude
WHO	World Health Organization

Abstract

Engaging in regular physical activity and limiting sedentary behaviour are effective ways for children and adolescents to gain short- and long-term health benefits. However, according to the vast majority of empirical studies assessing physical activity and sedentary behaviour with subjective and device-based instruments, most children and adolescents lead an unhealthy lifestyle with regard to their physical activity behaviour. Efforts to explain interindividual differences in physical activity by searching for generally relevant determinants in children and adolescents have led to inconsistent results across different studies. Intervention programmes trying to increase physical activity by targeting potential determinants via specific behaviour change techniques mostly provoke non-significant or small effects. Using data of female sixth graders attending German Realschule, this dissertation project addressed both the measurement and the explanation of physical activity by applying recent approaches that have rarely been used in previous research. In the first study, accelerometry was used to assess participants' physical activity and sedentary behaviour with high resolution and accuracy. Furthermore, the accelerometer sampling and processing criteria used in this study were compared to the criteria applied in previous large-scale national and international studies and implications of this comparison were discussed with regard to the accuracy of the results. In contrast to the traditional variable-based approach which is mostly applied to explain interindividual differences in physical activity, the second study used a person-oriented approach to find out how psychosocial resources affect physical activity behaviour of female sixth graders by their coexistence and interaction. To ensure that the measurement of potential psychosocial determinants of physical activity is as reliable as the assessment of physical activity itself, the third study illustrated a thorough multi-level validation of psychometric scales using the example of the German physical activity self-efficacy scale. Results of the first study indicated that while the average physical activity behaviour of the sample complied with the respective guidelines, sedentary behaviour was alarming. It was further discussed that the participants' physical activity scores would have been underestimated and sedentary behaviour scores would have been overestimated if accelerometer sampling and processing criteria of previous large-scale studies had been used. Consequences of biased physical activity and sedentary behaviour assessments were discussed with regard to the evaluation of the effectiveness of intervention programmes and the development of physical activity guidelines. The person-oriented approach applied in the second study identified three distinct profiles regarding the physical activity-related psychosocial resources. These profiles illustrated that participants who perceived more support by their physical education teacher regarding their basic psychological needs autonomy, competence and relatedness

were more satisfied in these needs during and outside of class, showed a physical activity motivation that is rather autonomously regulated, and had higher scores in self-efficacy and social support from friends and family. Furthermore, the profiles contributed to explanation of variance in moderate-to-vigorous physical activity. Results corroborated the assumption that psychosocial resources affecting physical activity do not develop independently from one another within a given person. Additionally, the capability of the person-oriented analysis in detecting potentials and deficits of groups of individuals within a sample was illustrated and its usefulness for the selection of tailored intervention components was discussed. Results of the third study underlined the appropriateness of multi-level validations of psychometric scales in case of nested data since representations of the construct of physical activity self-efficacy were identified both on the individual and the class level. Future research perspectives focused on the combination of recent approaches in measurement and explanation of physical activity to build a solid foundation for tailored interventions.

1 Introduction

Health status of children and adolescents is often described as worrying. Bad habits regarding nutrition (Diethelm et al., 2012), insufficient physical activity (PA) (Cooper et al., 2015; Guthold, Stevens, Riley, & Bull, 2020), large amounts of sedentary behaviour (SB) (Hallal et al., 2012) and overweight and obesity (Olds, Tomkinson, Ferrar, & Maher, 2010; Skinner & Skelton, 2014) are some of the most common concerns. PA is considered as one of the key aspects in promoting children's and adolescents' health, as an increase in PA also has a positive effect on other health parameters, such as weight status (Jago et al., 2020; Jiménez-Pavón, Kelly, & Reilly, 2010), cardiovascular health (Andersen, Riddoch, Kriemler, & Hills, 2011; Kriemler et al., 2008) or mental health (Ahn & Fedewa, 2011; Biddle, Ciaccioni, Thomas, & Vergeer, 2019). Therefore, an increase in PA is of incremental value over and above the mere PA level and thus has a large impact on overall health of children and adolescents.

Despite these well-known benefits of PA, a great number of studies measuring PA levels of children and adolescents conclude that PA behaviour is insufficient and most of the participants fail to fulfil the World Health Organization (WHO) guideline for PA of a daily average of 60 minutes moderate-to-vigorous physical activity (MVPA) (Bull et al., 2020; Demetriou et al., 2019; Finger, Varnaccia, Borrmann, Lange, & Mensink, 2018; Guthold et al., 2020). Although a wide concordance regarding insufficient PA levels in children and adolescents is striking, there are also several studies which report PA amounts above the level recommended by the WHO (e.g., Brooke, Corder, Atkin, & van Sluijs, 2014). Thus, there is a remarkable variance in the reported PA levels between different studies measuring PA, which must be explained in order to defend and corroborate the respective results.

There is a multitude of psychosocial models and theories that contribute to the explanation of PA behaviour or, more specifically, help to explain why one individual exhibits a different PA level than another individual (Buchan, Ollis, Thomas, & Baker, 2012; Rhodes, McEwan, & Rebar, 2019). Detailed knowledge about the constructs affecting PA behaviour is of great importance as it provides indications on what to focus when PA is supposed to be increased in a subsequent step. It is striking, however, that not only different theories comprise different determinants that are stated to be relevant for PA. Also, different empirical studies or reviews are inconsistent to some extent in their conclusion about which determinants are the most important ones for PA behaviour of the children and adolescents under study (Bauman et al., 2012; Craggs, Corder, van Sluijs, & Griffin, 2011; Uijtdewilligen et al., 2011). It is important to note that these inconsistencies do not necessarily weaken the respective studies and their different results. Rather, new approaches need to be

applied which are based on the acknowledgment of different results that emerge from data of different study samples. By embracing this notion, the expectation may not be to find generally important determinants of PA but to detect the determinants which exhibit a large potential for PA behaviour of the specific sample under study.

This dissertation thesis aims to find explanations why there are inconsistencies in existing literature regarding the reported PA level of children and adolescents and regarding the determinants suggested to be relevant for their PA behaviour. More specifically, the first objective is the implementation and discussion of specific accelerometer data sampling and analysis criteria that lead to the most accurate PA estimates in an adolescent study sample. The second objective is to apply a data analysis approach that illustrates how adolescent PA behaviour is driven by the coexistence and interaction of several psychosocial determinants within an individual, which may also disclose the respective PA-related potentials and deficits of specific groups of individuals. Fulfilment of these objectives may serve as a solid foundation for effective interventions in the field of PA since it can be detected whose PA should really be enhanced and which can be the most promising way of promotion. The respective analyses are conducted and discussed under consideration of recent approaches and recommendations in literature.

This work focuses on both children and adolescents since age of the examined sample in the presented empirical studies lies close to the proposed age limit between children and adolescents of ten years (Sawyer, Azzopardi, Wickremarathne, & Patton, 2018). A further reason is that age limits between childhood and adolescence are considered as slightly arbitrary anyway and should be taken with caution since an exact classification of an individual as a child or adolescent requires a consideration of the individual development and circumstances (Hardin, Hackell, & Simon, 2017). However, for reasons of readability, the term ‘adolescents’ is used in this work when it is referred to the studies included in this dissertation although it cannot be stated that the examined sample in fact exclusively comprised adolescents.

1.1 Relevance of Physical Activity and Sedentary Behaviour for Children and Adolescents

Regular PA helps to prevent overweight and obesity, decreases the risk of diseases like diabetes mellitus type II, colon and breast cancers or cardiovascular as well as mental diseases and eventually lowers the risk of premature death (Granger et al., 2017; McKinney et al., 2016; Warburton, Nicol, & Bredin, 2006). The effects of increased regular PA on physical health can be mediated by several biological mechanisms, such as positive changes in body composition, reduced blood pressure, improved coronary blood flow or an enhanced endothelial function. Additionally, PA also provokes positive changes on a mental

level, which again positively affects physical health status. Better psychological well-being provoked by regular PA further contributes to the prevention and treatment of cardiovascular and chronic diseases like osteoporosis or hypertension (Warburton et al., 2006). Furthermore, besides long-term effects of a routine engagement, there are also acute effects of PA, like a short-term reduction of blood pressure or enhanced glucose control (Thompson et al., 2001). In addition to positive short- and long-term effects on health, regular PA during childhood and adolescence also increases the probability of an active and healthy lifestyle later in adulthood in the sense of a tracking effect (Hallal, Wells, Reichert, Anselmi, & Victora, 2006; Telama, 2009).

SB is not simply defined as the lack of sufficient PA levels. Whereas this circumstance is described as physical inactivity, SB specifically comprises any waking behaviour whose energy expenditure does not exceed 1.5 metabolic equivalents and which is executed in a sitting, reclining or lying posture (Tremblay et al., 2017). Accordingly, SB incorporates harmful effects on health that are to some extent independent of the negative influence of physical inactivity (Biswas et al., 2015). German recommendations suggest to limit time for SB to no more than one hour per day during leisure time for children and to a maximum of two hours for adolescents (Rütten & Pfeifer, 2017). Higher levels in SB are associated with worse body composition, lower fitness or higher cardiometabolic risk (Carson et al., 2016). Fulfilling the WHO recommendation for daily MVPA may partly attenuate the health risks implied in high levels of SB (van der Ploeg & Hillsdon, 2017), so that detrimental health effects of SB more likely occur in individuals who, in addition to high SB levels, do not sufficiently engage in PA (Ekelund et al., 2016).

1.2 Status quo of Physical Activity and Sedentary Behaviour of Children and Adolescents

Referring to the vast majority of studies worldwide, only a small percentage of children and adolescents fulfil the WHO minimum guideline for MVPA. According to pooled analyses of self-report data, worldwide 19.7 % of adolescents aged 13 to 15 years and 19 % of students aged 11 to 17 years reached 60 minutes of daily MVPA (Guthold et al., 2020; Hallal et al., 2012). Analysis of accelerometer data of over 26,000 5-17 year olds from ten countries in Europe, Australia, North and South America suggested an even lower rate with 9 % of boys and 1.9 % of girls fulfilling the WHO guideline (Cooper et al., 2015). However, there are also studies whose results are more positive with regard to PA recommendations. In a systematic review comprising 36 studies mostly conducted in Europe and North America, average accelerometer-measured MVPA of schoolchildren was above the WHO recommendation (Brooke et al., 2014). Results further indicated a decline in MVPA from weekdays (82.3 minutes/day) to weekends (68.3 minutes/day) and exhibited a substantial

standard deviation in MVPA between the studies amounting to 44 minutes. This shows that results regarding the PA behaviour of children and adolescents not only differ between studies using different measurement instruments (i.e., self-report vs. accelerometer) but also between studies using the same instruments (Brooke et al., 2014; Cooper et al., 2015; Guthold et al., 2020).

The studies indicate a clear gender effect with girls suffering from an even higher risk of physical inactivity than boys (Cooper et al., 2015; Guthold et al., 2020; Hallal et al., 2012). In addition to this gender effect, PA decreases with age (Dumith, Gigante, Domingues, & Kohl, 2011; Van Hecke et al., 2016). Further effects of demographic variables, such as socioeconomic status (SES), have been suggested. Although respective analyses came to ambiguous conclusions (Corder et al., 2011; Molina-García, Queralt, Adams, Conway, & Sallis, 2017; Rhodes, Janssen, Bredin, Warburton, & Bauman, 2017; Sallis, Prochaska, & Taylor, 2000), German self-report data of almost 13,000 children and adolescents aged 3 to 17 years indicated a statistically significant negative relation between SES and the prevalence of less than two days with 60 minutes MVPA per week (Finger et al., 2018).

In line with PA values, recommendations regarding SB are mostly not fulfilled. Self-report data from 40 countries assessed in the Health Behaviour of School-Aged Children study showed that two thirds of adolescents aged 13 to 15 years already spent at least two hours per day only on watching television (Hallal et al., 2012). In more than half of the 34 countries represented in a study analysing SB data of over 70,000 schoolchildren, over one third of the students exhibited at least three hours spent on SB, with sedentary time during school hours and homework already excluded (Guthold, Cowan, Autenrieth, Kann, & Riley, 2010). Accelerometer-based results of the HELENA study conducted in ten European countries indicated a mean SB level for adolescents of around nine hours per day (Ruiz et al., 2011).

1.3 Measurement of Physical Activity and Sedentary Behaviour of Children and Adolescents

Reliable and valid measures of PA and SB are indispensable for a variety of reasons. Only with accurate measurements being available, studies can elicit insights into population-specific levels of PA and SB and their patterns, which refers to the way PA and SB are accumulated throughout a given time period like a day or a week in terms of timing, frequency and duration (Tremblay et al., 2017). Accurate measurements are also of high importance when examining the relation between PA and SB and health parameters and which amount of PA and SB are appropriate to gain positive health effects (Vanhelst et al., 2014). Furthermore, a high accuracy in PA and SB measurement is needed to draw

conclusions regarding which psychosocial and environmental factors determine PA behaviour. Finally, valid conclusions concerning the effectiveness of interventions promoting PA and reducing SB can only be drawn with reliable measures at hand (Loprinzi & Cardinal, 2011; Rachele, McPhail, Washington, & Cuddihy, 2012).

Additionally, measurement instruments should not only be highly reliable and valid but they should also be suitable to capture PA and SB of specific populations. In contrast to adults, PA behaviour of children and adolescents is characterized by intermittent patterns comprising short bouts of movement followed by short periods of SB (Bailey et al., 1995; Migueles et al., 2017).

Contrary to other health behaviours, PA and SB do not incorporate a precise biological marker that would disclose the individual's engagement in PA or SB (Trost, 2007). Therefore, methods have to be used which approximate and reflect PA and SB as exactly as possible. In the following, the most common methods to measure PA and SB are introduced and their respective advantages and limitations are described. The methods can be divided into subjective and device-based measures.

Subjective measures for PA and SB mostly comprise self-report, proxy-report and diaries (Loprinzi & Cardinal, 2011; Nigg et al., 2020; Rachele et al., 2012). Using self-report instruments, participants are asked by a self-administered questionnaire or by means of an interview to recall their PA and SB in a past time period. These approaches are often used in epidemiological studies with large sample sizes because financial and time-related costs are comparatively low. A further advantage is the possibility to ask for the type and context of PA or SB. However, the obvious limitations of self-report measures need to be taken into consideration. The provided information may be biased by interpretation of the items, social desirability or by inaccuracies in recall of past activities (Nigg et al., 2020). For children, it is even harder to accurately recall their PA as the often short and intermittent bouts of movement are difficult to remember and to summarize (Mattocks, Tilling, Ness, & Riddoch, 2008). On the other hand, they often overestimate both the amount and the intensity of PA (Slootmaker, Schuit, Chinapaw, Seidell, & van Mechelen, 2009). Therefore, validity of self-report measures is lower for children than for adolescents (Loprinzi & Cardinal, 2011; Nigg et al., 2020).

Alternative subjective measures that try to circumvent these problems are PA diaries or proxy-report measures (Loprinzi & Cardinal, 2011; Rachele et al., 2012). Asking parents or teachers to report a child's PA avoids the possible recall bias by the child. However, due to the obvious challenge of estimating PA levels of another person, validity of proxy reports are not substantially higher than when self-report measures are used (Loprinzi & Cardinal, 2011). With the use of PA diaries, a possible recall bias can be avoided as children are expected to track their PA and SB more regularly, and thus do not have to recall longer time

periods. However, diaries imply a higher burden for the children as they need to be compliant in frequently recording their behaviour. This might lead to substantial missing data in youth samples. Furthermore, even after elimination of the recall bias, PA diaries exhibit deficits in accuracy (Rachele et al., 2012).

The biological methods of heart-rate monitoring and indirect calorimetry belong to the category of device-based measures. Heart-rate monitoring is relatively inexpensive for researchers and unobtrusive for participants (Loprinzi & Cardinal, 2011; Rachele et al., 2012). A substantial limitation represents the dependency of heart rate on factors that are not necessarily related to PA, such as age, size, temperature, humidity, emotional stress or cardiorespiratory fitness. This may lead to a severe bias (Reis, den Tillaar, & Marques, 2011). Furthermore, there is a delay in heart rate response after a person has stopped being physically active. This implies an additional bias and makes heart-rate monitoring less suited for the assessment of the intermittent PA behaviour of children and adolescents (Loprinzi & Cardinal, 2011).

Indirect calorimetry is based on the measurement of oxygen consumption and carbon dioxide production. However, as reliability and validity of indirect calorimetry are rated as high, feasibility is low. Participants must wear a mask or a mouthpiece and a container to collect expired air, which makes it not suitable for the measurement of regular PA (Rachele et al., 2012; Sirard & Pate, 2001).

Accelerometers and pedometers represent device-based instrumental movement detection methods (Rachele et al., 2012). Due to their small size, light weight, high robustness and acceptable cost, accelerometers are increasingly used in assessments with relatively large samples of children and adolescents (Hänggi, Phillips, & Rowlands, 2013; Sherar et al., 2011). Recent generations of accelerometers record the acceleration of a human body in three axes (vertical, anteroposterior, mediolateral) with a high sampling frequency of up to 100 Hz and reflect these accelerations by means of activity counts. In a next step, these counts are summed over epochs of different lengths, e.g., 1 second, 15 seconds or 60 seconds. Using corresponding software, wear-time validation of the accelerometer data is conducted to differentiate wear-time periods and non-wear-time periods. To get a representative image of everyday PA and SB, assessments often take one week to ensure that the participants wear the devices for at least three weekdays and one weekend day, with usually at least eight hours of wear time being necessary for a valid day. In a last step, the wear-time validated data sets are entered into a prediction equation and subsequent cut points for activity counts are used to determine the duration of PA in different intensities, such as light, moderate, vigorous and moderate-to-vigorous PA. Accelerometer results indicate a high correlation with values collected by means of indirect calorimetry, however, with a much higher feasibility for the participants. Additionally, use of

accelerometers in specifically assessing SB has been repeatedly suggested (Burchartz, Anedda, et al., 2020; Loprinzi & Cardinal, 2011; Migueles et al., 2017; Rachele et al., 2012). To ensure accurate and valid results, it is important to choose cut points using short epoch lengths, and thus offer a high resolution. Furthermore, the applied sampling and processing criteria should match the ones that had been used in the original validation of the selected cut points. At the same time, the choice of activity cut points represents the main limitation of accelerometers, as results can substantially differ according to the applied cut points (Kim, Beets, & Welk, 2012; Migueles et al., 2017; Rachele et al., 2012).

Pedometers provide an often used and cheaper alternative to accelerometers. The most severe limitation of pedometers, however, is that pedometers do not allow for analyzing PA with regard to its different intensities. A drawback shared with accelerometers is the inability to accurately measure movements and energy expenditure while cycling, weight lifting and rather stationary (e.g., push-ups) or water-based activities (Loprinzi & Cardinal, 2011; Rachele et al., 2012).

One of the most labour-intensive methods to measure PA and SB is direct observation (Loprinzi & Cardinal, 2011; Rachele et al., 2012). Observers have to be trained to accurately and objectively code participants' PA. Direct observation represents a highly reliable and valid instrument to assess the different intensities of PA in children and adolescents. Additionally, it can be applied in all kinds of settings and activities and also provides information about the social and physical context in which activity takes place, such as behavioural prompts by significant others and available equipment or facilities. However, the amount of time that has to be invested when preparing and conducting the assessments argues against its application, especially when PA and SB of larger samples are to be assessed over a longer period of time (Rachele et al., 2012).

The use of doubly-labelled water finally represents the most accurate assessment of energy expenditure (Loprinzi & Cardinal, 2011; Rachele et al., 2012). After ingesting two types of stable isotopes, the energy expenditure for a time period of up to two weeks can be measured by calculating the difference between the elimination rates of the isotopes. However, although being considered as the gold standard in the assessment of energy expenditure, the method of doubly-labelled water does not serve to specifically measure the duration and intensity of PA.

In the end, several aspects have to be taken into consideration when searching for the most appropriate instrument for the assessment of PA and SB in empirical studies. Age of the participants, sample size and the time frame of assessments play major roles. Furthermore, there needs to be a good trade-off between the reliability and validity of the methods and the respective burden that is imposed on the participants by its application (Dollman et al., 2009; Loprinzi & Cardinal, 2011). Equally important, one needs to make

sure that the PA information of interest, e.g., duration, intensity, type or context of PA, is provided in the output of the chosen method (Trost, 2007). Especially when measuring PA and SB of a youth sample, the chosen method not only needs to be highly valid but must be age appropriate, easy to use and imply minimal participant burden in order to have a high participant compliance (Trost, Marshall, Miller, Hurley, & Hunt, 2007).

1.4 Explanation of Physical Activity and Sedentary Behaviour of Children and Adolescents

In view of the unhealthy PA and SB levels that are widely reported (e.g., Cooper et al., 2015; Ruiz et al., 2011), a strong need to increase PA and reduce SB of children and adolescents emerges. However, health behaviours like PA and SB cannot be directly improved by interventions, but via a change in some personal, social or environmental variable closely related to the behaviour. As soon as these variables are identified, interventions can be designed in order to provoke changes in these constructs, which may eventually result in successful behaviour change (Baranowski, Anderson, & Carmack, 1998; Sallis & Owen, 1999). Since PA and SB are complex behaviours, it comes naturally that interindividual differences in these behaviours cannot be explained by a small number of factors or solely one theoretical model. Rather, different models and theories including partially different constructs add to each other and contribute their part to the explanation of interindividual variance in PA and SB. In the following, an overview comprising the theories mostly used for the explanation and promotion of PA in children and adolescents is given. In a next step, independently of theoretical models, a brief summary based on reviews of previous evidence will highlight the most relevant constructs for PA explanation and promotion in children and adolescents.

1.4.1 Most Popular Theories for Explanation and Promotion of Physical Activity and Sedentary Behaviour of Children and Adolescents

Until the late 1980s, studies about PA behaviour were mostly atheoretical and yielded an incohesive variety of determinants that were examined separately from one another (Rhodes et al., 2019). This led to different definitions of these constructs and a severe lack of knowledge about the relationships between the determinants of PA (Rhodes & Nigg, 2011). Together with the insight that mere information about the amount of necessary PA for leading a healthy life was not sufficient to enhance PA behaviour, theoretical frameworks were introduced that incorporated several factors relevant for PA at once. These frameworks should finally contribute to the explanation and promotion of PA. In the past three decades, social-cognitive approaches, humanistic approaches, dual-process

approaches and socioecological approaches were the four main theoretical frameworks that have been used in the explanation and promotion of PA (Rhodes et al., 2019).

The social-cognitive approach is the framework most often applied in the explanation of PA (Camacho-Minano, LaVoi, & Barr-Anderson, 2011; Rhodes et al., 2019). Generally, it proclaims that engagement in a certain behaviour depends on two aspects. First, expectations regarding the outcome of the behaviour, like possible benefits or barriers, determine the personal relevance of the behaviour. Second, the estimation of the personal capability, represented by constructs like self-efficacy (Bandura, 1997; Bauman et al., 2012), finally lead to the intention of engaging in the behaviour (Rhodes et al., 2019). However, the use of the social-cognitive approach in promotion of PA yields only limited success as the effect sizes in interventions targeting social-cognitive constructs as potential mediators of an increase in PA are on average small (Rhodes et al., 2019; Williams & French, 2011). The popularity of the social-cognitive framework mainly traces back to the fact that it implies constructs like self-efficacy, which are consistent correlates of PA behaviour (Bauman et al., 2012; Craggs et al., 2011). Furthermore, the rationale of public health to enable health benefits for the population is perfectly in line with the basic idea of the social-cognitive framework which assumes that engagement in a certain behaviour depends on its potential benefits. However, the pronounced imbalance between the widespread knowledge about the benefits of regular PA on the one hand and actual PA prevalence on the other hand questions the suitability of this notion with regard to PA promotion to some extent (Rhodes et al., 2019).

The humanistic framework implies theories which assume that behaviour is not only led by possible rewards or punishments, but is mainly driven by inherent human needs (Rhodes et al., 2019). Within this framework, the self-determination theory (SDT; Ryan & Deci, 2000) is the theory most often applied in PA research (Rhodes et al., 2019). SDT represents a motivational macro-theory comprising six micro-theories. Thereby, it not only refers to the quantity but also to the quality of motivation. The SDT differentiates between six different types of motivation, whose regulation is arranged on a continuum of self-determination. The situation when a person completely lacks any motivation is referred to as amotivation. If behaviour is regulated by external factors like rewards or penalties, the person is externally motivated, which represents the least autonomous form of motivation. When a person has internalized an external motivation to some degree, it is referred to as introjection. Behavioural regulation is driven by identified motivation when a person engages in a certain behaviour because of personal values and the perceived relevance of the behaviour. Identified motivation is the first type on the self-determination continuum which is allocated to autonomous motivation. Autonomous forms of motivation are completed by integrated and intrinsic motivation. The difference between these two lies

within the type of outcome that is aimed at. In case of intrinsic motivation, a person acts solely because of enjoying the respective activity. When behaviour is regulated by integrated motivation, the person aims for an additional outcome apart from having fun or enjoyment. Besides its detailed perspective on quantitative and qualitative aspects of motivation, a further advantage of the SDT lies within its concrete instructions on how to promote motivation (Buchan et al., 2012). According to the SDT, the basic psychological needs (BPN) autonomy, competence and relatedness have to be satisfied for a human to experience self-determined motivation. The need for autonomy is fulfilled when a person experiences a sense of volition and personally conforms to the norms of the environment. Competence is given if a person feels capable to meet given challenges by means of the own competence. Relatedness describes the need to feel connected to significant others (Deci & Ryan, 2000; Ryan & Deci, 2017). Autonomous motivation should finally promote the respective behaviour (Deci & Ryan, 2000). This assumption has been supported with regard to PA behaviour (Owen, Smith, Lubans, Ng, & Lonsdale, 2014; Teixeira, Carraça, Markland, Silva, & Ryan, 2012). The solid theoretical and empirical foundation as well as its usefulness in planning and conducting interventions mainly contribute to the popularity of the SDT (Buchan et al., 2012; Teixeira et al., 2012). Indeed, the BPN serve as viable tools that can relatively easily be used by key stakeholders like exercise leaders or physical education (PE) teachers to increase autonomous motivation and, in a last step, PA behaviour of their students (Chatzisarantis & Hagger, 2009; Kelso et al., 2020; Standage, Gillison, Ntoumanis, & Treasure, 2012). Critique regarding the SDT refers to whether BPN are limited to autonomy, competence and relatedness, since there are further psychological constructs, such as the experience of variety, which might be equally relevant for human motivation and could add to the previously proposed BPN in the explanation of PA behaviour (Sylvester et al., 2016). Another limitation often found in SDT-based PA research is the inconsistency in the measurement and examination of self-determined motivation. Although SDT proclaims a continuum of self-determined motivation from controlled to autonomous regulation, in practice, participant scores are usually reported for each of the six behavioural regulations included in the continuum and not for the superordinate magnitude of self-determined motivation (Markland & Tobin, 2004). This approach, in turn, is in line with the assumption that human PA behaviour is driven by more than one reason or construct at the same time. Still, an overwhelming majority of researchers examine independent effects of the different behavioural regulations instead of analyzing their coexistence and interactions within a given person (Bergman & Lundh, 2015; Emm-Collison, Sebire, Salway, Thompson, & Jago, 2020; Lindwall et al., 2017; Yli-Piipari, John Wang, Jaakkola, & Liukkonen, 2012).

Dual-process frameworks differentiate between two distinct processes which are assumed to determine human behaviour by means of their interaction. Type-1 processes comprise, for example, habits or automatic evaluations. These processes are fast, non-conscious and occur automatically requiring only minimal cognitive resources, which finally makes them difficult to control. Type-2 processes represent more controlled reasoning, require more cognitive resources, and refer to intentions, values or expectations, and thus mostly comprise variables of the social-cognitive framework (Brand & Ekkekakis, 2018; Evans & Stanovich, 2013; Rhodes et al., 2019). Dual-process models usually assume that behaviour is rather guided by automatic type-1 processes unless enough type-2 resources, like self-control, are given (Brand & Ekkekakis, 2018; Evans & Stanovich, 2013). A strength of dual-process models lies within its potential to explain why people are often not sufficiently physically active despite having formed the intention to do so, therefore representing a complementary element to social-cognitive approaches in the explanation of PA (Rhodes et al., 2019). However, the mapping of PA determinants into reflective and automatic processes likely oversimplifies the complex interactions of determinants that finally lead to PA behaviour. Therefore, it is recommended to better use dual-process models as a heuristic which may describe several influences on PA on a continuum from completely reflective to completely automatic processes (Rhodes et al., 2019).

According to the socioecological framework, factors influencing health behaviours like PA and SB can be categorized into five different levels: the intrapersonal level (e.g., gender, intrapersonal psychological constructs), the interpersonal level (e.g., group processes), organizational level (e.g., schools), community level (e.g., built environment, local infrastructure) and the policy level (e.g., laws) (Rhodes et al., 2019; Sallis & Owen, 2015). Research based on the socioecological framework has mainly focused on the organizational, community and policy levels since intrapersonal and interpersonal level influences are elaborately examined in PA research based on other popular approaches like the social-cognitive or humanistic framework (Teixeira et al., 2012; Williams & French, 2011). It is assumed that the five levels of the socioecological framework affect behaviour directly and indirectly as well as via an interaction of their respective factors (Craggs et al., 2011). The size of the effects on PA and SB of the more proximal factors of the intrapersonal level are usually larger compared to factors of the social or built environment (Rhodes et al., 2019). Support for statistically significant effects of between-level interactions on PA is sparse (Rhodes, Saelens, & Sauvage-Mar, 2018). Still, the socioecological framework enjoys great popularity, especially in recent years. One practical reason is that the focus on environmental and policy aspects provides local authorities and governments with an adequate framework to intervene and try to improve health behaviours of the population as a whole instead of affecting only smaller groups of individuals. Furthermore, the multi-level

structure of the socioecological framework reflects the prevailing notion in western societies of a shared comprehensive responsibility for the population's health behaviour between the actors on the different levels of influence (Rhodes et al., 2019). The main drawback of the socioecological framework is probably illustrated best by the example of a person who freely chooses not to be physically active although having the opportunity, equipment and facilities to do so. This may exemplify the relatively poor incremental explanation of PA variance of environmental-level factors over and above the contribution of individual-level factors, such as motivation, self-efficacy or self-regulation (Bauman et al., 2012; Rhodes et al., 2017; Rhodes et al., 2019). Furthermore, the breadth of socioecological models regarding the number of included levels and factors is at the expense of their precision and finally their ability of providing concrete, deducible mechanisms through which PA and SB of individuals may be effectively changed (Buchan et al., 2012).

As there is no clear evidence that PA interventions in youth are more effective when their design is based on a specific theoretical model (Rhodes et al., 2017), it is worthwhile to have a closer look at determinants of behaviour change in PA and SB, independently from theoretical considerations or models.

1.4.2 Most Relevant Constructs for Explanation and Change of Physical Activity and Sedentary Behaviour of Children and Adolescents

Over the past decades, a main endeavour of PA and SB research was to summarize the evidence regarding constructs which are consistently related to PA and SB of children and adolescents. Several researchers collected previous evidence regarding correlates of PA and SB by conducting quantitative systematic reviews. In a next step, several 'reviews of reviews' summarized the findings of previous quantitative systematic reviews and presented the most consistent correlates of PA usually classified into five categories (Sallis & Owen, 1999). Regarding demographic and biological correlates, the reviews of reviews by Biddle and colleagues (Biddle, Atkin, Cavill, & Foster, 2011), Bauman et al. (2012) and Sterdt et al. (Sterdt, Liersch, & Walter, 2014) identified gender as a consistent correlate of PA, with boys being more physically active than girls. Furthermore, age was also regarded as a negative correlate especially for adolescents (Biddle et al., 2011; Sterdt et al., 2014). Additionally, Sterdt and colleagues (2014) identified parental education, family income and SES as positive correlates of adolescent PA. With regard to psychological constructs, self-efficacy was the only consistent correlate for children and adolescents outlined by the study by Bauman et al. (2012). Sterdt et al. (2014) tended to support this finding and added intention to be physically active and goal orientation as consistent PA correlates for children and adolescents, respectively. Biddle et al. (2011) reported inconsistent findings regarding self-efficacy and identified competence perception as the most important PA correlate for

adolescents. As an important behavioural correlate, previous PA was a consistent correlate in children and adolescents. Additionally, participation in organized sports and, especially for children, a healthy diet were reported as positive PA correlates in two of the three studies (Biddle et al., 2011; Sterdt et al., 2014). According to all three reviews of reviews, parental support was the most consistent sociocultural correlate. Sterdt et al. (2014) further identified support from friends or significant others as a positive correlate of PA in children. Concepts referring to the availability and proximity of and the access to recreational areas and facilities were the environmental correlates most consistently reported in the three studies. Moreover, time spent outdoors was identified as an important correlate especially for children in two studies (Biddle et al., 2011; Sterdt et al., 2014). Further environmental correlates that have been inconsistently reported are walkability, traffic speed and volume, residential density or PA-related policies in schools (Bauman et al., 2012; Sterdt et al., 2014).

A construct is classified as a correlate when its relation to cross-sectional differences in PA or SB is consistently supported. However, a construct that is deemed a correlate does not necessarily have the power to affect PA or SB as a causal factor that may improve health behaviour. The implicated goal of research on factors associated to PA and SB is the change of these behaviours in order to gain health benefits. Therefore, it is important to identify constructs that are not only related to PA and SB, but to change in PA and SB. In other words, instead of focussing on cross-sectional correlates of PA and SB, research has started to examine determinants of changes in PA and SB (Baranowski et al., 1998). The systematic reviews of Craggs et al. (2011) and Uijtdewilligen et al. (2011) have summarized the empirical evidence from prospective studies examining determinants of PA and SB change in children and adolescents. Although the two systematic reviews were based on the same categories of constructs (Sallis & Owen, 1999), only a small number of constructs that have been reported as cross-sectional PA correlates could be confirmed as determinants of longitudinal behaviour change (Bauman et al., 2012; Biddle et al., 2011; Sterdt et al., 2014). Craggs and colleagues (2011) reported that for individuals aged 10 to 13 years, previous PA and self-efficacy were positively related to change in PA. For adolescents aged 14 years and older, higher scores on perceived behavioural control, social support and self-efficacy were associated with a smaller decline in PA. Uijtdewilligen et al. (2011) found moderate evidence for intention as a consistent determinant of PA change in children. For adolescents, there was moderate evidence for planning and previous PA as significant determinants. Furthermore, in complete contrast to previous findings on PA correlates, Uijtdewilligen and colleagues (2011) identified age as a positive determinant of adolescent PA, also based on moderate evidence. Thus, mostly constructs from psychological and social domains were identified as consistent determinants of PA

change in children and adolescents (Sallis & Owen, 1999). Regarding SB, the amount of prospective research was small, especially in adolescents. Therefore, the authors concluded insufficient evidence for all potential determinants of change in SB (Uijtdewilligen et al., 2011).

1.5 Psychometric Measurement of Constructs Related to Physical Activity and Sedentary Behaviour of Children and Adolescents

Just as important as it is to measure PA and SB by tools exhibiting high reliability and validity, it is fundamental to assess potential correlates and determinants of PA and SB by using appropriate, thoroughly validated psychometric instruments. When using psychometric scales in samples of children and adolescents, questions regarding the participants' cognitive and communicative skills necessary for completing questionnaires might emerge (Bell, 2007). Deficits in these prerequisites can prevent participants from providing reliable and valid answers. In order to appropriately respond to items of psychometric scales, participants have to go through four cognitive stages. First, the participant needs to understand the used terms and must know what has to be done to answer the question. Second, the information necessary to respond to the item needs to be recalled. Third, the retrieved information has to be evaluated, which is followed by the last stage, the communication of the response (Schwarz & Sudman, 1996). If items are not appropriately designed for the examined sample, chances are higher that one or more of the cognitive stages are missed out, which finally leads to a deficit in response behaviour (Bell, 2007). Thus, the quality of the items determines the quality of the responses. When thoroughly and appropriately designed, questionnaire assessments are feasible for younger children, starting around the age of seven. Adaptations are necessary until the age of 16, when adolescents are considered to be able to respond to adult questionnaires (Scott, 1997).

To design high-quality items appropriate for use in samples comprising children and adolescents, some general rules should be followed. The items should be kept short, formulations should be simple and straightforward. Items of inverse formulation should be avoided in children questionnaires. To minimize social desirability effects, items should not be phrased in a suggestive way (Bell, 2007). The ability of the participants to differentiate between a variety of response options should be considered. Adolescents aged 11 years or more are usually able to respond by using 5-point scales (Borgers, de Leeuw, & Hox, 2000). Furthermore, every point should be labelled, not only the two extremes (Borgers, Hox, & Sikkel, 2003).

Before psychometric scales are first used to assess PA- and SB-related determinants, they should be thoroughly validated in samples that match the examined

individuals in later assessments with regard to specific characteristics like age or school type (Craggs et al., 2011). Furthermore, if clustered data are available, such as data of students nested in classes, a multi-level validation of the used scales is recommended since ignoring the clustered nature of the data might lead to wrong parameter estimates, standard errors and model fits. Furthermore, reliability of measures, factor structures or estimations of criterion validity might differ between the individual level and the group level (Huang, 2017; Julian, 2001).

1.6 Different Methodological Approaches in the Explanation of Physical Activity Behaviour

There are two fundamentally different approaches when attempting to explain interindividual variance in PA behaviour. The variable-oriented approach represents the traditional way by examining relations of different variables on a between-person level (Bergman & Andersson, 2010). A typical finding produced by this type of analysis would be that individuals with a higher score on intrinsic motivation, compared to the average of the sample, tend to exhibit lower scores on extrinsic motivation and, with regard to behaviour, higher-than-average PA levels (Teixeira et al., 2012). Thus, the variable-based approach examines average relations and effects across a given population (Bergman & Andersson, 2010).

The person-oriented approach, on the other hand, addresses the assumption that the different constructs determining human behaviour do not develop independently of one another. Instead, it is proposed that these determinants affect behaviour of an individual via a complex interplay within the respective person (Bergman & Lundh, 2015). Hence, in contrast to the variable-based approach, the primary focus of person-oriented analyses lies on the individual instead of on the population as a whole. Whereas the variable-based approach implicitly assumes that individuals are legitimate representations of a single homogeneous population they form part of, the person-oriented approach explicitly builds upon the proposed existence of subgroups within a population that are characterized by specific differences on the variables of interest (Bechter, Dimmock, Howard, Whipp, & Jackson, 2018). Consequently, the main purpose of person-oriented analyses is to identify homogeneous groups of individuals, so-called profiles, that exhibit similar patterns across a variety of assessed variables (Bechter et al., 2018; Bergman & Lundh, 2015; Gut, Schmid, & Conzelmann, 2020). Each profile consists of members with homogeneous patterns that are distinct from the patterns of the members of other groups. Therefore, the person-oriented approach is suited for the investigation of both within-person interactions and between-person differences. Differences between profiles can consist of level or shape effects (Lindwall et al., 2017; Morin & Marsh, 2015). Level effects refer to quantitative

differences in the case of one profile exhibiting equally higher scores on every assessed variable compared to another cluster. Shape effects are characterized by qualitative differences, that is, profiles differ with regard to the way the assessed variables interact with each other, thus forming different kinds of patterns. Besides, antecedents and outcomes of profile membership may be examined (Bechter et al., 2018). This means it can be analyzed which preceding factors lead to an individual forming part of a specific profile regarding the variables of interest. Likewise, it can be examined how membership in a specific profile affects outcomes like PA behaviour.

1.7 Critique of Previous Research

With regard to the several requirements that have to be met when measuring PA and SB of children and adolescents, such as a high feasibility and relatively low participant burden or the provision of several output categories like duration and intensity of PA, accelerometers have become a popular choice in research focused on PA and SB of these age groups (Migueles et al., 2017). Popularity of accelerometers yet not only traces back to the fulfilment of these requirements. Most importantly, accelerometers implicate the necessary features for a highly reliable and valid assessment of the specific intermittent activity behaviour of children and adolescents (Loprinzi & Cardinal, 2011; Trost, 2007; Trost et al., 2007).

However, in previous studies using accelerometry, the full potential for highly accurate and valid assessments of PA and SB of children and adolescents has hardly been tapped. By applying a high sampling frequency in all three axes and adequate wear-time requirements for participants during the sampling process as well as short epoch lengths and appropriate wear-time algorithms and activity cut points in data processing, accelerometers provide the possibility to assess PA and SB with high resolution and accuracy (Migueles et al., 2017). However, an overwhelming majority of large-scale national and international studies has applied sampling and processing criteria that lead to less accurate and finally less valid data on PA and SB of children and adolescents. The German GINI and IDEFICS studies, for instance, used an epoch length of 60 seconds and measured accelerations only in vertical direction (Konstabel et al., 2014; Pfitzner et al., 2013). The German KiGGS study indeed used vector magnitude (VM) counts, i.e., considering activity counts of all three axes, but applied a 15-second epoch length (Burchartz, Manz, et al., 2020; Woll et al., 2019). The European HELENA and ENERGY projects applied a 15-second epoch length on vertical acceleration data (Chinapaw et al., 2014; Ruiz et al., 2011). These decisions implicate a lower resolution in sampling and processing of accelerometer data, and thus result in lower accuracy.

Therefore, it is assumed that in previous studies, PA is likely to be underestimated and SB scores are likely to be higher than in reality (Banda et al., 2016; Keadle, Shiroma, Freedson, & Lee, 2014; Migueles et al., 2017). Since an accurate assessment of PA and SB is no end in itself, but is of high relevance for the evaluation of the effectiveness of interventions (Loprinzi & Cardinal, 2011) or the question at which levels health benefits can be expected to emerge (Vanhelst et al., 2014), it is an absolute necessity to conduct accelerometer assessments that contribute to precise estimates of PA and SB of children and adolescents.

However, previous studies not only exhibit deficits in measurement of PA and SB. With regard to the way differences in PA behaviour are usually explained, a clear imbalance in the selection of the methodological approach appears (Emm-Collison et al., 2020; Lindwall et al., 2017). On the one hand, there is ample support for a variety of constructs affecting PA (e.g., Craggs et al., 2011). In line with that, theories for the explanation or promotion of PA include several determinants altogether (Rhodes et al., 2019). On the other hand, appropriate methods which could actually examine how different determinants affect PA behaviour of an individual via their coexistence and interaction have hardly been applied. Instead, the traditional variable-based approach was used in the vast majority of research, which analyzed the relevance of different determinants separately in order to find out which might be the most important ones when seen from a population perspective (Bergman & Andersson, 2010). When examining the simultaneous influence of different PA determinants, the variable-based approach implies some general statistical drawbacks, such as the problem of multicollinearity when including several correlated predictors at the same time (Vatcheva, Lee, McCormick, & Rahbar, 2016). In addition, when applied in studies that want to explain PA behaviour based on theories like the SDT, which explicitly proclaim the coexistence and interaction of different motivational types within one individual, the variable-based approach seems even less appropriate. By use of this approach, the naturally occurring multidimensionality comprising the coexistence and interactions of different psychosocial determinants that take place within a person cannot be tested (Emm-Collison et al., 2020). For instance, it cannot be examined if a person benefits from several motivational sources, if certain combinations of behavioural regulations add to each other or have detrimental effects with regard to actual PA behaviour. Consequently, by means of the variable-based approach, it cannot be found out if there are subgroups within a population who exhibit specific interactional patterns regarding their motivation for PA.

In order to gain new insights that may provide a complementary contribution to the findings of variable-based research, person-oriented analyses have become more popular in recent years. Since the theoretical assumptions of the SDT are perfectly in line with the scope of application of the person-oriented approach, an increasing body of SDT research

in the field of PA has conducted person-oriented analyses. Studies could support the assumed simplex pattern regarding the different behavioural regulations proposed by the SDT, meaning that individuals with higher scores on autonomous regulations usually had lower scores on controlled forms of regulation. Additionally, most studies found profiles that provided new insights by conflicting to some extent with theoretical assumptions (e.g., PA behaviour of an individual being driven by both autonomous and controlled forms of regulation) (Bechter et al., 2018; Emm-Collison et al., 2020; Lindwall et al., 2017). Furthermore, it was shown that motivational profiles were related to actual PA behaviour (e.g., Emm-Collison et al., 2020). Although popularity of the person-oriented approach increased especially in SDT-based research, still none of the studies has examined profiles of motivation and their association to accelerometer-assessed PA in an adolescent sample. In view of the necessity of age-specific insights and the concerns of self-report measures of PA, it is highly relevant to fill this research gap by use of appropriate methods.

1.8 Aims of the Studies

The instruments mostly used for measuring PA and SB are subjective self-report questionnaires and, representing device-based measures, accelerometers (Loprinzi & Cardinal, 2011). When comparing the output of these two measurement techniques, it is often stated that children and adolescents tend to overestimate the duration and intensity of PA when asked to report about it themselves (e.g., Slootmaker et al., 2009). However, one should question the rationale of such comparisons given that accelerometer measurements are subject to severe biases as well and therefore exhibit substantial deficits in accuracy (Migueles et al., 2017). These biases become apparent when looking at the reported PA levels and patterns of different accelerometer studies, which cannot exclusively be explained by true differences in the respective samples under study (e.g., Brooke et al., 2014; Pfitzner et al., 2013; Ruiz et al., 2011). Intervention programmes and public health campaigns trying to promote PA of children and adolescents are prompted by the alarming results of large-scale national and international studies measuring PA behaviour by means of different instruments. However, in view of the severe deficits in PA assessment of previous studies, it has to be noted that a solid foundation for these programmes and large-scale campaigns in the form of highly accurate PA measurements is missing. While this refers to PA behaviour of a population as a whole, accurate assessments of individual PA behaviour is equally important to be able to differentiate risk groups from non-risk groups in terms of physical inactivity. Therefore, the first aim of this work was to conduct a highly accurate PA and SB assessment of adolescents by accelerometry and to discuss the implications of different decisions in accelerometer data sampling and processing criteria with regard to their effect on accuracy.

After a precise identification of groups being at risk for physical inactivity, one needs to find effective ways to successfully promote PA. As a preceding step, person-oriented analyses can corroborate the results of accelerometer analyses, since they are able to shed light at the psychological and social resources of individuals. Thus, groups can be identified who are not only at risk in terms of actual PA behaviour, but who also exhibit the greatest demand with respect to deficits in their resources which finally determine PA behaviour (Sallis & Owen, 1999). These high-risk groups can then be prioritized when it comes to informing strategies for intervention (Bechter et al., 2018). Since different profiles do not respond equally to a general intervention programme, in a next step, practitioners have to design tailored interventions. Here, person-oriented analyses can serve as a starting point, as they reveal the unique deficits and demands of several homogeneous groups which can then be addressed more specifically (Gut et al., 2020; Hagger, 2010; Lindwall et al., 2017). First evidence has indicated that the regulation of PA behaviour is dynamic, which means that individuals move from one motivational profile to another over time (Emm-Collison et al., 2020). Tailored interventions should try to deliberately guide individuals from profiles of low motivation and unhealthy PA behaviour to profiles of higher motivation and activity. Therefore, the second aim of this work is to conduct a person-oriented analysis on psychosocial determinants of PA in order to elucidate the respective potential and deficits of different profiles, which might serve as a starting point for the design of tailored intervention strategies.

Since the psychosocial determinants of PA behaviour should be measured by means of previously validated age-appropriate psychometric scales (Craggs et al., 2011), a subordinate aim of this work was to conduct thorough validations of translated and adapted scales. Methodology and results are exemplified through the validation of the German physical activity self-efficacy scale.

2 Methodology

The studies presented here were conducted within the framework of the CReActivity project. Primary goal of the project was to promote PA levels of female sixth-graders attending German Realschule, since they constitute a risk group for physical inactivity with regard to gender, age and SES (Cooper et al., 2015; Finger et al., 2018; Nold, 2010). Students could participate if they did not have any acute injuries or other clinical diagnoses preventing them from being physically active. Mean age of the sample was 11.6 years. The participants were on average normal weight and exhibited a medium SES. The intervention was implemented in PE. Therefore, PE teachers were provided with fully elaborated lesson plans that were specifically designed to support students' BPN while following the curriculum with regard to

the content of the lessons (Demetriou & Bachner, 2019). To evaluate the effectiveness of the intervention as well as possible mediating mechanisms, a variety of constructs was assessed at three measurement points. BPN support in PE was measured with the Adolescent Psychological Need Support in Exercise Questionnaire (APNSEQ; Emm-Collison, Standage, & Gillison, 2016). Adapted versions of the Basic Psychological Need Satisfaction and Frustration Scale (BPNSFS) by Chen et al. (2015) were used to assess students' BPN satisfaction in the contexts of PE and leisure time. Quantity and type of motivation was assessed using the Behavioural Regulation of Exercise Questionnaire 2 (BREQ-2; Markland & Tobin, 2004). PA self-efficacy and social support from family and friends were measured with scales developed by Dishman and colleagues (2010). PA and SB were assessed by means of accelerometers (Actigraph models GT3X - wGT3X-BT).

In the following, the specific methods used in the respective studies are described in more detail.

2.1 Study 1

The original sample for the accelerometer assessments of PA and SB in study 1 comprised 545 female sixth graders. Assessments took place in schools in and around the city of Munich, where the main study of the CReActivity project was conducted. In the pilot study testing the feasibility of accelerometer assessments in female sixth graders, also students attending schools in Tübingen and Freiburg were included. Analyses for study 1 referred to baseline data of the CReActivity main study and data from the preceding pilot study.

The systematic review by Migueles and colleagues (2017) served as the main foundation for choosing the following accelerometer data sampling and processing criteria. Students had to wear the devices on the right hip for seven consecutive days. Devices were taken off during sleep and water-based activities. Sampling rate was set at 30 Hz. During data download, VM activity counts were summed over 1-second epochs in order to guarantee a high resolution. Low frequency extension filter was not used. The algorithm by Choi, Liu, Matthews and Buchowski (2011) was used for wear-time validation. Thus, 90 minutes without any activity counts were classified as non-wear time, with up to two minutes of temporary activity being tolerated if there were no activity counts in the 30-minute windows before and after this allowance period. PA data of a participant was valid if the devices were worn for at least eight hours on at least three weekdays and one weekend day. The final sample comprised 425 female sixth graders with valid PA data. In a last step, wear-time validated data were analyzed with the Hänggi cut points to calculate the average daily duration for each participant of SB, light PA and MVPA (Hänggi et al., 2013). These cut points were chosen since the sampling and processing criteria used by Hänggi and

colleagues to validate the cut points match the ones used in our study, which eliminates respective artefacts in our results.

Statistical data analysis was performed in SPSS, version 25 (IBM Corp., 2017). Means and standard deviations of SB and the different PA intensities were presented for an average weekday, weekend day and for an average day considering the respective amount of valid weekdays and weekend days for each participant. In order to examine patterns of PA and SB throughout weekdays and weekend days, the hourly means of valid cases were incorporated into a diagram. Weekday-weekend differences were tested by Wilcoxon tests since the distributions of PA and SB on weekdays and weekends differed slightly from a normal distribution.

2.2 Study 2

To identify homogeneous profiles regarding PA-related psychosocial constructs within the participants of the CReActivity project, a self-organizing maps (SOM) analysis was conducted with the MATLAB R2018a programme and the SOM toolbox for MATLAB (Kohonen, 1995; Vesanto, Himberg, Alhoniemi, & Parhankangas, 1999). SOM analysis implicates several advantages that were useful for this study (Herrero-Herrero, García-Massó, Martínez-Corralo, Prades-Piñón, & Sanchis-Alfonso, 2017). It is based on an unsupervised algorithm for a potentially non-linear data structure, thus representing an explorative approach. The statistical power is not affected by the number of included input variables. It creates superordinate profiles with a higher accuracy than regularly used clustering techniques (Budayan, Dikmen, & Birgonul, 2009; Melo Riveros, Cardenas Espitia, & Aparicio Pico, 2019). Furthermore, SOM presents results in both numerical and graphic form, which allows for an easy detection of specific subgroups that might differ to some extent from the superordinate cluster they form part of.

The seventeen psychosocial constructs named above were used as SOM input variables. Valid data of 475 female sixth graders who participated in the baseline assessment of the CReActivity project were available. The distinct profiles are built with regard to the similarities of participants on the input variables. To do so, SOM procedure comprises three steps (Pellicer-Chenoll et al., 2015): (1) the construction of a neuron network, (2) the initialization of the SOM, when each neuron is assigned a value or weight for each input variable in two different manners (i.e., randomized and linear initialization), and (3) the training, when the initial values or weights of the neurons are iteratively modified, which is led by two different training algorithms (i.e., sequential and batch) (Oliver Gasch et al., 2018). Based on its values on the input variables, every participant is represented by an input vector. These input vectors are introduced to the network of neurons, who then try to gather the input vectors by adapting their own weight vectors according to the input vectors.

The neuron which manages to adapt its weight vector in a way that it exhibits the smallest Euclidean distance to the input vector, finally gathers the input vector. The adaptation magnitude of the neurons is affected by neighbourhood functions which influence the extent to which a winning neuron may adapt better to a given input vector than the neurons further away in the network. In the end, each neuron has a weight vector that is most similar to the input vectors it has successfully gathered (Estevan, García-Massó, Molina-García, & Barnett, 2019). This process was repeated with the number of iterations set to 100. Furthermore, four different neighbourhood functions were used. Thus, with regard to the two initialization methods, the two training algorithms and the four neighbourhood functions, 1600 SOMs were created (i.e., 100 x 2 x 2 x 4). In the end, the SOM with the smallest error is selected (Estevan et al., 2019). The number of superordinate profiles depends on the quantization error, i.e., the average Euclidean difference between the input vectors and the cluster vectors they are allocated to (Kohonen, Nieminen, & Honkela, 2009), and the number of participants per cluster, which should be large enough to reflect common profiles.

2.3 Study 3

To illustrate the adaptation and validation of psychometric scales by recent methods, the physical activity self-efficacy scale by Dishman et al. (2010) was translated into German, adapted in terms of wording and finally validated by using a multi-level approach. Since the assessed students were nested in classes, nature of the data was clustered. In this case, the use of multi-level validation is recommended because the assumption that individual perceptions are independent of one another cannot longer be maintained (Feltz, Short, & Sullivan, 2008; Huang et al., 2015). Ignoring the clustered nature of data could lead to biased parameter estimates, false inferences regarding the psychometric properties and finally wrong conclusions about the reliability and validity of the scale (Dedrick & Greenbaum, 2011; Julian, 2001). Therefore, validation was conducted in accordance with the multi-level approach described by Huang (2017). Items were translated by means of a combination of the committee approach and the pretest procedure (Brislin, 1970; Cha, Kim, & Erlen, 2007). Valid data on the physical activity self-efficacy scale was provided by 507 female sixth graders during the baseline assessments of CReActivity. To examine the factor structure of the scale, a multi-level confirmatory factor analysis (MCFA) was conducted by use of an R syntax within the lavaan package (Rosseel, 2012). This provides the opportunity to examine individual and group-level data simultaneously. To do so, the total population covariance matrix is divided into a pooled within-group covariance matrix and a between-group covariance matrix. To evaluate model fit, the $\chi 2$-likelihood ratio statistic, the comparative fit index, the Tucker-Lewis index, the root mean square error of approximation, the standardized root mean square residual and Akaike's information criterion were

considered (Hu & Bentler, 1999; Korner-Nievergelt et al., 2015). To estimate scale reliability, Cronbach's alpha was calculated separately for the individual and the class level using the alpha function of the psych package in R (Revelle, 2017). Criterion validity was examined by multi-level correlations with MVPA.

3 Publications

3.1 Article 1

Authors: Joachim Bachner, David J. Sturm, & Yolanda Demetriou

Title: Accelerometer-Measured Physical Activity and Sedentary Behavior Levels and Patterns in Female Sixth Graders: The CReActivity Project

Journal: International Journal of Environmental Research and Public Health

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Summary:

Since previous studies about PA and SB of children and adolescents in Germany and Europe led to highly inconsistent results, the aim of the first article was to conduct an accurate accelerometer assessment of PA and SB while setting a strong focus on discussing the implications of different sampling and processing criteria in accelerometer assessments. PA and SB levels of 545 female sixth graders participating in the CReActivity project were assessed. Their patterns of PA and SB throughout the day were examined and differences between weekdays and weekend days were analyzed. Sampling and processing of accelerometer data adhered to recent recommendations which, to the author's knowledge, neither had been applied to data of a German-speaking sample nor in European or worldwide large-scale studies before. PA behaviour was better than expected with regard to previous German and international studies. The WHO recommendation of a daily average of 60 minutes MVPA was fulfilled by 90.4 % of the girls on weekdays and by 57.4 % on weekend days. The significant weekday-weekend differences were mainly associated to active commuting to and from school. SB of the participants was worrying due to more than 8 hours of sedentary time on weekdays and over 7 hours on weekend days. Results indicate a strong need for multi-component interventions to find solutions that enable students to reduce sedentary time during school hours and engage in less sedentary activities with family and friends on weekends. With the application of sampling and processing criteria used in previous German and international studies, PA and SB levels would have been measured with a smaller resolution and accuracy leading to biased PA and SB estimates. This questions previous findings on PA and SB and highlights the necessity of large-scale representative studies that follow the most recent recommendations regarding accelerometer-based measurements. Only then, an accurate and valid differentiation between PA-related risk groups and non-risk groups is possible.

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Contribution:

Joachim Bachner was the leading author of the article. Yolanda Demetriou and Joachim Bachner engaged in acquisition of funding. Yolanda Demetriou developed the idea for the study. David J. Sturm and Joachim Bachner collected the data. Joachim Bachner and Yolanda Demetriou developed the study design. Joachim Bachner conducted the data analysis and wrote the article in its published form. His co-authors contributed to manuscript revision.

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Article

Accelerometer-Measured Physical Activity and Sedentary Behavior Levels and Patterns in Female Sixth Graders: The CReActivity Project

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Abstract: Regular physical activity (PA) and low levels of sedentary behavior (SB) have positive health effects on young people. Adolescent girls of low socioeconomic background represent a high-risk group with regard to physical inactivity and SB. In this study, accelerometer-measured levels of PA and SB of female sixth graders attending lower secondary schools in Germany are presented, patterns of PA and SB throughout the day are described and differences between weekdays and weekend days are analyzed. Data of 425 students of the CReActivity project were analyzed. Sampling and processing of accelerometer data followed recent recommendations, which had not been applied to data of a German-speaking sample before. The WHO recommendation of daily 60 min moderate-to-vigorous PA was fulfilled by 90.4% of the girls on weekdays and by 57.4% on weekend days. The significant weekday–weekend differences were mainly associated with active commuting to and from school. Students engaged in SB for more than 8 h on weekdays and for over 7 h on weekend days. The results suggest a strong need for interventions increasing PA and reducing SB, especially during school hours and on weekends. Furthermore, a comparison with methods and results of previous studies highlights the need to follow recent criteria in accelerometer data sampling and processing to ensure an accurate and valid differentiation between PA-related risk groups and non-risk groups.

Keywords: accelerometry; secondary school; female; sedentariness; activity

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1. Introduction

The World Health Organization (WHO) recommends that children and adolescents aged 5 to 17 years engage in moderate-to-vigorous intensity physical activity (MVPA) for an average of 60 min per day [1]. In Germany, the recommendations are even higher, emphasizing that children and youth should accomplish at least 90 min of daily MVPA [2]. Recent systematic reviews suggest that children who follow these recommendations are at a lower risk of overweight or obesity, type II diabetes mellitus and metabolic syndrome and have higher fitness levels than children who do not meet the MVPA recommendations [3,4].

When recommendations on physical activity (PA) are not fulfilled, the person's behavior is classified as physical inactivity. However, physical inactivity is not the same as sedentary behavior (SB). Instead, SB specifically comprises any waking behavior that is characterized by an energy expenditure of $\leq$1.5 metabolic equivalents (METs) while being in a sitting, reclining or lying posture (e.g., use of electronic devices while sitting, reclining or lying; sitting at school or in public transport) [5]. Sedentary time (ST) indicates the time spent in sedentary behaviors. The SB pattern finally indicates how a person accumulates SB throughout a given time period, such as a day or a week, while being awake. These patterns refer to the timing, duration and frequency of sedentary bouts, i.e., time periods of uninterrupted ST and breaks between sedentary bouts [5]. Canadian and American recommendations emphasize that for gaining health benefits, children (aged 5–11

years) and youth (aged 12–17 years) should limit recreational screen time to no more than 2 h per day and limit sedentary motorized transport, extended sitting time and time spent indoors throughout the day [6]. According to the German recommendations, children should spend a maximum of 60 min sedentary per day and adolescents a maximum of 120 min per day during recreational time [2]. A school child can both accumulate ten hours of ST during a school day and fulfill PA recommendations by going for a 60 min run in the evening. In this case, the child would accumulate an unhealthy amount of ST but would not be classified as physically inactive. Thus, physical inactivity and SB represent different aspects of PA behavior, which to some extent imply different risk factors for health. Sufficient MVPA levels may only compensate for the health risks of high ST levels to a certain degree [7]. Higher ST is associated with unfavorable body composition and behavioral conduct, higher clustered cardiometabolic risk, lower fitness and lower self-esteem in boys and girls [8].

PA and SB are complex multifactorial behaviors that are difficult to assess. Hence, to obtain accurate data, device-based measures of PA and SB are recommended. The use of self-report questionnaires to determine ST and MVPA reveals some, but not all, relationships between PA and health risk factors [9]. Triaxial accelerometers, such as the Actigraph GT3X+, are one of few devices of sufficient sensitivity to detect small movements during sitting and standing. Although they are not free of shortcomings, such as inadequate measurement while cycling or swimming or the dependence of PA values on different approaches in collecting and processing accelerometer data (e.g., sampling rate, cut points for different PA intensities), accelerometers have become the preferred choice for assessing different levels of PA in children and adolescents [10].

Internationally, the use of accelerometers to assess PA and SB in children is increasing [11]. However, the 2018 German Report Card on Physical Activity of Children and Youth, which aims to evaluate and benchmark the national PA promotion efforts in children and adolescents, showed that in Germany these studies are sparse [12].

Self-report data from wave two of the population-based German National Health Interview and Examination Survey for Children and Adolescents (KiGGS) revealed that 22.4% of the girls and 29.4% of the boys between 3–17 years met the WHO recommendations [13]. In the German national Health Behaviour in School-aged Children (HBSC) survey (2013/14), self-report data received from 11 to 15-year-olds showed that only 14% of girls and 19.9% of boys were physically active at moderate-to-vigorous intensity for at least 60 min per day [14]. So far, only three studies provided PA data of larger samples of children and adolescents with accelerometers. The Identification and prevention of dietary- and lifestyle-induced health effects in children and infants study (IDEFICS) conducted accelerometer measurements of PA of children aged two to ten years (N = 1037, mean age = 6.5 years). The proportion reaching 60 min MVPA on a daily basis was 14.0% for girls and 33.3% for boys [15]. The German Infant Nutrition Intervention Programme study (GINIplus) asked potential participants at the age of 15 to take part in accelerometer assessments (N = 269, mean age = 15.5 years, SD = 0.3). The WHO recommendation was fulfilled by 17.2% of the girls and 24.9% of the boys [16]. In wave two of the KiGGS study, PA was assessed with self-report questionnaires (N = 12981) and, in a subsample, with accelerometers (N = 2278). Initial results of accelerometer data analysis showed that 19.7% of the girls and 36.6% of the boys aged 6 to 17 years exhibited 60 min daily of MVPA [17]. These numbers reflect the typically found effects of gender and age [18], indicating that on average, boys and younger children are more active than girls and older adolescents, respectively.

Similarly, only a few studies that assess SB of children and adolescents living in Germany in a device-based manner exist. Self-report data from the KiGGS and HBSC studies in Germany showed that 60.4 to 72.3% of boys and 55.6 to 57.8% of girls spent more than two hours per day watching TV and using electronic media [14,19]. Based on their study, Huber and Köppel [20] concluded that children and adolescents spent 71% of their awake time on weekdays and 54% on weekend days sedentary. Finally, based on

accelerometer data from the GINIplus and IDEFICS studies, children and adolescents spent roughly two thirds of their awake time in a sedentary position [15,16].

PA levels and SB for children vary throughout the day as well as between weekdays and weekends. On average, school children are more active on weekdays than on weekend days [21]. Furthermore, on weekdays, peaks of PA can be seen during the commute to school in the morning, during lunch break and directly after the end of school hours [22]. Additionally, PA and SB levels and patterns of children and adolescents vary between countries due to cultural and environmental differences [18].

According to the socioecological framework, health behaviors like PA and SB can be influenced by factors at the intrapersonal level (e.g., gender or psychological constructs), interpersonal level (e.g., group processes), organizational level (e.g., schools), community level (e.g., built environment, local infrastructure) and policy level (e.g., laws). It is further assumed that behavior is affected by direct, indirect and interactive effects of the respective levels [23]. Although the most proximal factors of the intrapersonal level seem to be more influential on PA and SB compared to factors of the social or built environment, responsibility for the population's health behavior is supposed to be shared between the actors from the different levels of influence [23,24]. In line with this notion, family and school represent the two main settings where interventions to increase PA and reduce SB of school children are conducted [25]. Within the school setting, numerous PA programs have been conducted, including a substantial number of intervention studies that generated positive effects on accelerometer-measured PA. These programs can be further divided into classroom-based interventions [26], interventions during recess [27], interventions focusing on active school transport [28] and after-school interventions [29]. As a first step toward the development of a potentially effective intervention program, it is necessary to differentiate in which situations or settings PA should be promoted in order to appropriately respond to existing deficits and challenges [25]. Therefore, understanding differences in PA and SB of German students during the day and over the course of the week is of importance when planning interventions. Thus, the aim of this contribution is (a) to describe the level of ST, light physical activity (LPA) and MVPA in a sample of female sixth graders in Southern Germany, (b) to report the percentage of students complying with the WHO recommendations of MVPA (60 min per day) and the German recommendations of MVPA (90 min per day) and ST (less than two hours per day), (c) to provide an overview of patterns of PA and ST throughout the day and d) to analyze differences between weekdays and weekends in these values and patterns. The study focuses on female sixth graders of lower secondary schools as they represent a specific risk group for physical inactivity in terms of gender, age and socioeconomic status (SES) [13,18]. It was assumed that the majority of female students did not meet the WHO and German recommendations regarding MVPA and ST. Furthermore, MVPA levels were expected to be higher on weekdays compared to weekend days, including peaks for transport to and from school.

Insights are generated through an analysis following the most recent recommendations of accelerometer-related literature [30], which to date have not been applied to data of a German-speaking sample. Comparisons to existing studies analyzing PA and SB in children and adolescents in Germany, Europe and worldwide, as well as implications of different decisions regarding sampling and processing of accelerometer data, are discussed in detail.

2. Materials and Methods

2.1. Participants

The original sample comprised 622 sixth graders (77 boys; 12.4%) aged 11 to 12 years from 20 schools. The schools belonged to two kinds of German secondary schools (Realschule and Gymnasium), which represent an intermediate and high secondary education, respectively. Sample recruitment took place both in and around (distance <25 km) the cities of Munich, Tübingen and Freiburg, as there were enough members of the research team regularly at site to guarantee an economic and flexible sampling process with respect to

the schedules of school principals, teachers and students. Every student free of any acute injuries (e.g., broken leg) and clinical diagnoses prohibiting PA could participate in the study. Participation rate was 74.1%. The main reasons for not being willing to take part in the study were children's doubts regarding their outer appearance when wearing the accelerometers and their concerns that the devices might hinder their performance and enjoyment when being physically active.

For the most part, data assessments took place in the context of the CReActivity intervention study focusing on the promotion of girls' PA [31]. The intervention was implemented in single-sex female physical education (PE) in the sixth grade of lower secondary schools. This school type was chosen because of its higher portion of students with a lower SES compared to other types of secondary schools in Germany [32]. Further details about the intervention program can be found in the study protocol [31]. The data used for the present analysis were taken from pilot studies testing the feasibility of accelerometer assessments (including girls and boys) and from the baseline assessments of the intervention study.

The minimal sample size was calculated under consideration of the intended increase in MVPA provoked by the intervention. Furthermore, using a formula by Rutterford et al. [33], the estimated intracluster correlation, the supposed variation in class sizes and the levels of significance and power were considered as well. Sample size calculation resulted in a minimum of 467 students being required.

The original sample size of 622 students was diminished by failure or loss of assessment devices or by children not wearing the devices for the required amount of time, resulting in invalid measurements. Furthermore, due to their small number, data of boys were excluded to avoid a remarkable imbalance regarding gender that might have led to a bias in the results. Eventually, 425 female sixth graders constituted the sample for the PA data analysis. Average BMI (kg/m^2) of the final sample was M = 19.5 (SD = 3.7; N = 282). The number of students participating in the measurements for the BMI was reduced by students refusing to get weighed because they were afraid that their classmates might find out about their weight. This concern applied to both apparently normal-weight and overweight girls, although each student was separated from the class for the measurements. SES was assessed by questions concerning the parents' current jobs. The answers were classified by means of the International Socioeconomic Index of Occupational Status (ISEI) based on the International Standard Classification of Occupation 2008 (ISCO-08) [34]. When both parents were employed, the job with the higher ISEI was considered (HISEI). The HISEI of the final sample ranged between 15 and 89 with a mean value of 50.5 (SD = 16.0; N = 360). HISEI could not be calculated for every participant because of vague answers which made precise classifications impossible.

The dataset analyzed for this study is provided as supplementary file S1.

2.2. Measures

Physical Activity

PA was measured with accelerometers (ActiGraph models GT3X to wGT3X-BT; Pensacola, FL, USA). A small part of the sample (46 students) was assessed with the GT3X model, while the vast majority wore newer models. The agreement regarding PA outcomes between the different generations of ActiGraph models used in this study was high, with the differences in MVPA values measured with different models being close to zero [35]. The recent systematic review of Migueles et al. served as the main foundation for choosing the accelerometer data collection and processing criteria [30].

The devices were worn on the right hip with an elastic belt. Hip placement was chosen since it classifies PA behavior at least as accurately as wrist placement, with the wearing compliance being comparable for both placements [36]. The participants had to wear the accelerometers for at least seven consecutive days. On weekdays children put on the devices when they started their way to school at the latest, on weekend days they put them on right after getting up. The accelerometers had to be worn all day long, except during

water-based activities, until 9 p.m. or until they went to bed. ActiLife (v. 6.13.3, ActiGraph, Pensacola, FL, USA) was used for initialization of accelerometers and the processing of the assessed data. The sampling rate was set to 30 Hz.

When downloading the data from the accelerometers, all three axes (vertical, horizontal, medio-lateral) were used to calculate the vector magnitude (VM) activity counts, which were summed over 1-s epochs (10-s epochs for the GT3X model because of lower battery and memory capacity), considering the intermittent activity behavior of children [30]. Furthermore, choosing a short epoch length means that the resulting resolution of the measurement is higher [37]. VM was calculated as the square root of the sum of the three axes' squared activity counts [38]. Data filtering with the ActiLife low frequency extension (LFE) was not applied.

As a next step, wear-time validation of the data was conducted with the algorithm by Choi, Liu, Matthews and Buchowski [39]. Although the Choi et al. algorithm is most popular in adult samples, it was used in this study. It classifies periods of at least 90 min without any activity counts as non-wear time counts. Up to two minutes of temporary activity are tolerated in the classification of a period as non-wear time as long as there are 30-min windows with no activity counts before and after this allowance period [39]. This is a more liberal non-wear time definition, since data are not excluded before there is more than 90 min of zero activity. Instead, these periods are considered as ST. By choosing a longer non-wear time definition, risk groups like adolescents with a higher BMI, who are of special interest when investigating PA, are retained in the analysis to a greater extent. Since they might show longer periods of ST, the risk of misclassifying these periods as non-wear time is lower when more liberal non-wear time definitions are used [30]. Hence, while accepting a decrease in activity counts per minute (CPM), the chosen non-wear time definition prevents the potential loss of data of important risk groups [30]. A participant's PA data were considered as valid if data were available for at least three weekdays and one weekend day, with at least eight hours of wear time (WT) being required for a valid day. These criteria were seen as a good compromise between obtaining valid PA values and at the same time retaining a comprehensive sample preserving the study's power [30]. Applying these constraints, 78.0% of the participants included in this study provided valid PA data (425 out of 545 girls).

In a last step, the wear time-validated activity data were analyzed by means of the cut points provided by Hänggi, Phillips and Rowlands to eventually calculate the average duration of ST, LPA and MVPA for the respective periods of interest for each participant [10]. Based on counts per minute (60-s epoch) and counts per second (CPS; 1-s epoch), respectively, the cut points were: less than 180 CPM/3 CPS for ST, 180 to 3360 CPM/3 to 56 CPS for LPA and more than 3360 CPM/56 CPS for MVPA. So for every epoch it is checked whether the respective cut point is exceeded. Then, the epochs in which the cut points are exceeded are added, which finally leads to values normally reported in minutes per day. To obtain accurate values it is important to use cut points which, first of all, offer the most precise assessment and, secondly, were validated using the same criteria in collecting and processing PA data as we used [30]. The cut points from Hänggi et al. were validated with a sample of similar age wearing the devices (GT3X) on the right hip and a 1-s epoch length was used to sum up the VM activity counts without applying the LFE filter. Additionally, raw vector magnitude counts per minute (VMCPM) were given to indicate values which were free from the influence of subsequent transformations or analyses [38].

According to the wearing guidelines described above, PA between 5 a.m. and 9 p.m. was considered for the PA data analysis. In this way, the activities of participants who got up early were included.

2.3. Procedure

Before eligible schools were contacted, the study and its associated data assessments were approved by the ethics commission of the Technical University of Munich, registered

under 155/16 S, and the Ministry of Cultural Affairs and Education of the state of Bavaria in Germany.

Then, schools of the eligible school forms which were in and around the cities where enough manpower was provided were contacted and could participate voluntarily. After the schools had indicated a general willingness to take part in the study, several weeks before the scheduled beginning of the data assessment, students and their parents were informed in writing about the purpose and the procedure of the assessments. Students did not participate unless they and their parents had provided written consent beforehand. Participation in the assessments was voluntary and neither schools nor students were rewarded in any way. Not taking part did not lead to any consequences for schools or students.

Data were assessed during autumn and winter in 2016, 2017 and 2018. Data assessments started at the beginning of a school lesson. Codes were used to ensure the anonymity of the participants. Before the distribution of the accelerometers, members of the assessment team explained how to put them on. At least 25% of the participants of each class (or more, if there were more volunteers) were handed out a single-sided information sheet explaining how to handle the accelerometers. These students then served as contact persons for the upcoming assessment days in case their classmates had questions, like when and how to wear the devices. Furthermore, the volunteers were to remind their classmates to wear the accelerometers regularly and correctly throughout the assessment days. After one week, the accelerometers were collected in school by a member of the assessment team.

2.4. Data Analysis

Statistical data analysis was performed in SPSS, version 25 [40]. PA behavior was described by the means and standard deviations for ST, LPA, MVPA and VMCPM. Additionally, the average wear time for valid days was calculated. Every descriptive statistic was given for an average weekday, weekend day and for an average day considering the respective amount of valid weekdays and weekend days for each participant. Based on the mean values of each participant, the percentage of girls fulfilling the WHO and German recommendations regarding MVPA per day was calculated. To examine patterns of PA and SB throughout the day, the hourly means of valid cases were incorporated into a diagram. The distribution of the ST and PA values at weekdays and weekend days differed slightly from a normal distribution. Although the sample could be considered large enough to still allow the application of parametric tests, differences between the values of weekdays and weekend days were compared with a Wilcoxon test. To be able to test for differences in PA intensity between weekdays and weekend days, the change in percent of WT and MVPA from weekday to weekend was calculated as well as the respective portion of ST, LPA and MVPA during WT. Discernible differences in the ST and MVPA patterns for weekdays and weekend days were further analyzed by first building new variables (e.g., for periods > 1 h). As the distributions in the periods of interest differed significantly from a normal distribution, the differences between weekdays and weekend days were again tested with Wilcoxon tests. Effect sizes r were classified using the criteria from Cohen, which consider $r > 0.1$ a small effect, $r > 0.3$ a medium effect and $r > 0.5$ a large effect [41].

3. Results

Table 1 shows the means and standard deviations of ST and PA behavior as well as the average WT for valid days. Figure 1 shows the percentage of the girls that met the WHO and German recommendation for MVPA on weekdays and weekend days, respectively. Whereas 90.4% reached the WHO recommendation of 60 min of MVPA during weekdays, this number diminished to 57.4% for an average weekend day. The German MVPA recommendation of 90 min of MVPA was fulfilled by 42.1% on a weekday and 19.8% on a weekend day. Additionally, on a weekday only 6 of 425 students (1.4%) managed to limit their ST during recreational time (between 4 and 9 pm) to less than two hours. On a weekend day, no one accumulated less than two hours being sedentary.

Table 1. Sedentary and physical activity behavior in minutes and in percent of wear time (mean (SD)) on average weekdays, weekend days and in total (N = 425).

	Weekday	Weekend Day	Wilcoxon Test Z-Value, Effect Size r	Total
ST/day (min)	515.0 (72.5)	434.8 (91.6)	−14.07 ***, 0.48	493.7 (67.6)
LPA/day (min)	177.0 (50.4)	147.0 (51.6)	−13.10 ***, 0.45	168.7 (47.2)
MVPA/day (min)	87.5 (23.2)	68.4 (30.2)	−13.20 ***, 0.45	82.3 (22.4)
VMCPM (min)	875.2 (225.3)	855.2 (323.3)	−2.72 **, 0.09	867.9 (221.9)
WT/day (min)	779.4 (57.5)	650.1 (94.7)	−16.21 ***, 0.56	744.6 (50.7)
ST/WT (%)	66.0 (7.7)	66.9 (9.9)	−2.56 *, 0.09	66.3 (7.6)
LPA/WT (%)	22.7 (6.4)	22.6 (7.4)	−0.63, 0.02	22.7 (6.3)
MVPA/WT (%)	11.2 (2.9)	10.5 (4.4)	−5.39 ***, 0.18	11.1 (2.9)

Note. SD = standard deviation; min = minutes; ST = sedentary time; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; VMCPM = vector magnitude counts per min; WT = wear time on valid days; */**/*** = *p*-values for difference between weekday and weekend day <0.05/<0.01/<0.001.

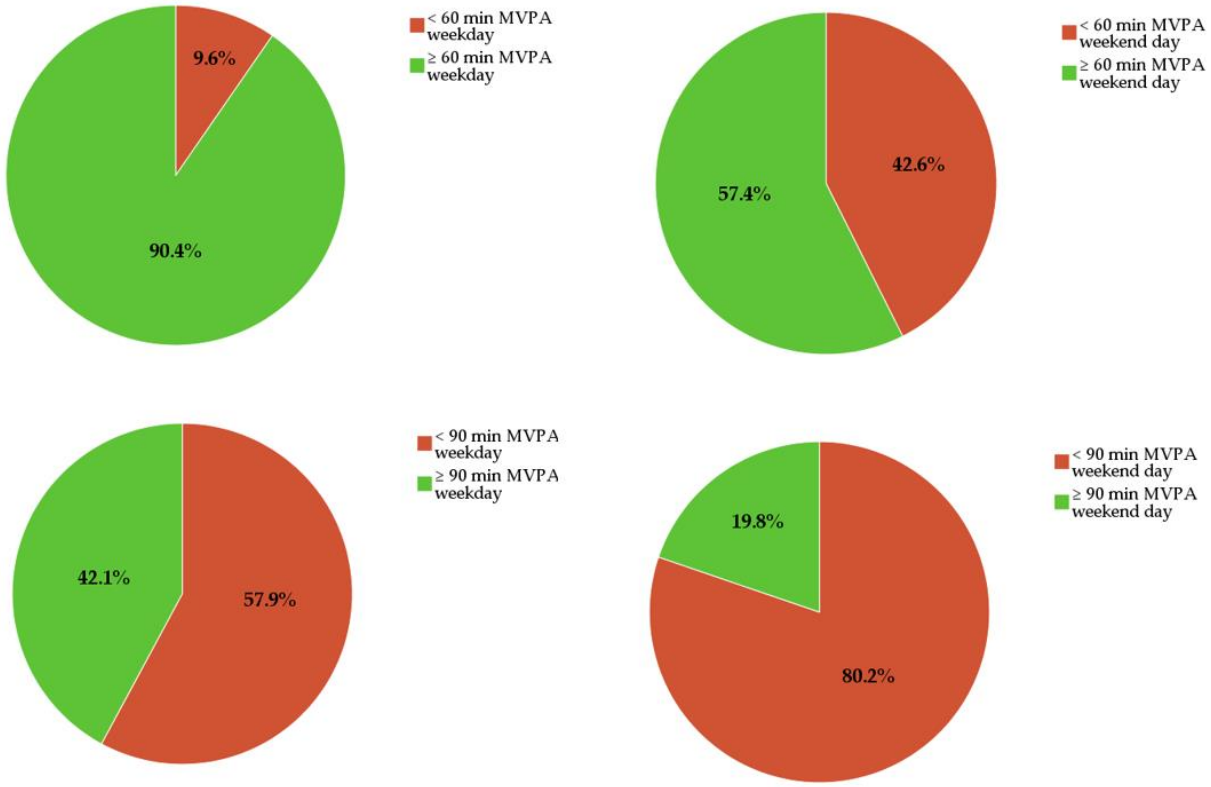

Figure 1. Percentages of the sample fulfilling the respective PA recommendations. Green = recommendation fulfilled, red = recommendation not fulfilled; MVPA = moderate-to-vigorous physical activity.

Table 1 not only indicates that the girls' MVPA values showed a significant decline from weekdays to weekend days ($z = -13.20$, $p < 0.001$, $r = 0.45$), but that ST ($z = -14.07$, $p < 0.001$, $r = 0.48$), LPA ($z = -13.10$, $p < 0.001$, $r = 0.45$) and the average WT for a valid day ($z = -16.21$, $p < 0.001$, $r = 0.56$) also dropped to a similar extent. Furthermore, a comparison of the VMCPM between weekdays and weekend days showed significantly less counts per min on weekend days ($z = -2.72$, $p < 0.01$, $r = 0.09$). This raised the question of whether the adolescents' PA behavior was less intense on weekend days or if this behavior was only performed for a smaller amount of time for the participants getting up later on weekend days compared to weekdays. To answer this question, the extent of the decrease in MVPA and WT from weekdays to weekend days was compared. The decline in percent

of MVPA was significantly larger than that of WT (z = −5.62, $p < 0.001$, r = 0.19). Likewise, the portion of MVPA during WT was higher on weekdays compared to weekend days (weekdays = 11.2%, weekend days = 10.5%; z = −5.39, $p < 0.001$, r = 0.18). While there was no difference regarding LPA (weekdays = 22.7%, weekend days = 22.6%; z = −0.63, $p = 0.53$), there were more girls with a higher portion of ST during WT on weekend days than on weekdays (weekdays = 66.0%, weekend days = 66.9%; z = −2.56, $p < 0.05$, r = 0.09).

Figure 2 shows the adolescents' SB and PA patterns on weekdays and weekends. Between 6 a.m. and 1 p.m., the girls accumulated about 100 min more ST on weekdays than on weekend days (weekdays = 251.78, weekend days = 148.56; z = −16.89, $p < 0.001$, r = 0.58). MVPA was higher on weekdays compared to weekend days, especially in the time periods between 7 a.m. and 8 a.m. (weekdays = 9.53, weekend days = 0.38; z = −17.73, $p < 0.001$, r = 0.61), as well as between 1 p.m. and 2 p.m. (weekdays = 10.11, weekend days = 6.21; z = −12.77, $p < 0.001$, r = 0.44).

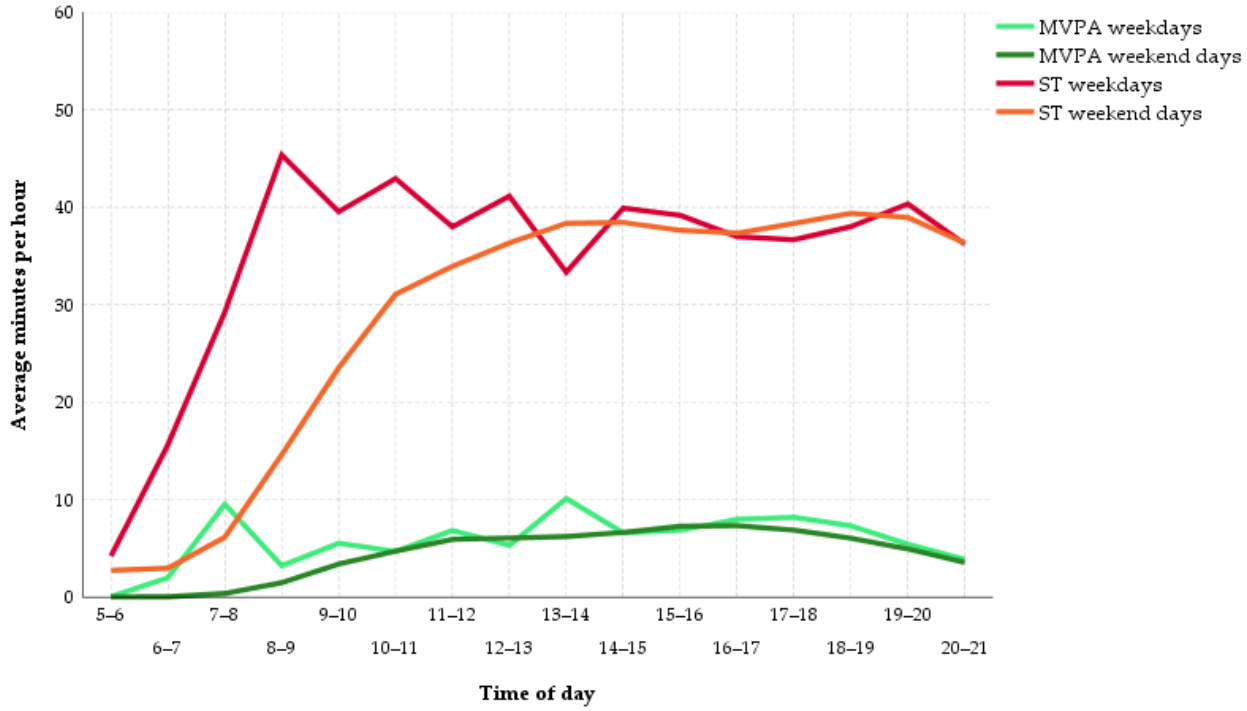

Figure 2. Sedentary behavior (SB) and moderate-to-vigorous physical activity (MVPA) patterns on weekdays and weekend days. ST = sedentary time.

Figure 3 displays the PA pattern based on VMCPM. The scale of the *y*-axis ranges from VMCPM representing no activity to the upper limit of LPA defined by the cut points from Hänggi et al. (3360 VMCPM). The main differences in average VMCPM between weekdays and weekends can be observed between 6 a.m. and 8 a.m. (weekdays = 930.28, weekend days = 93.80; z = −17.54, $p < 0.001$, r = 0.60) and between 1 p.m. and 2 p.m. (weekdays = 1201.09, weekend days = 852.74; z = −11.17, $p < 0.001$, r = 0.38).

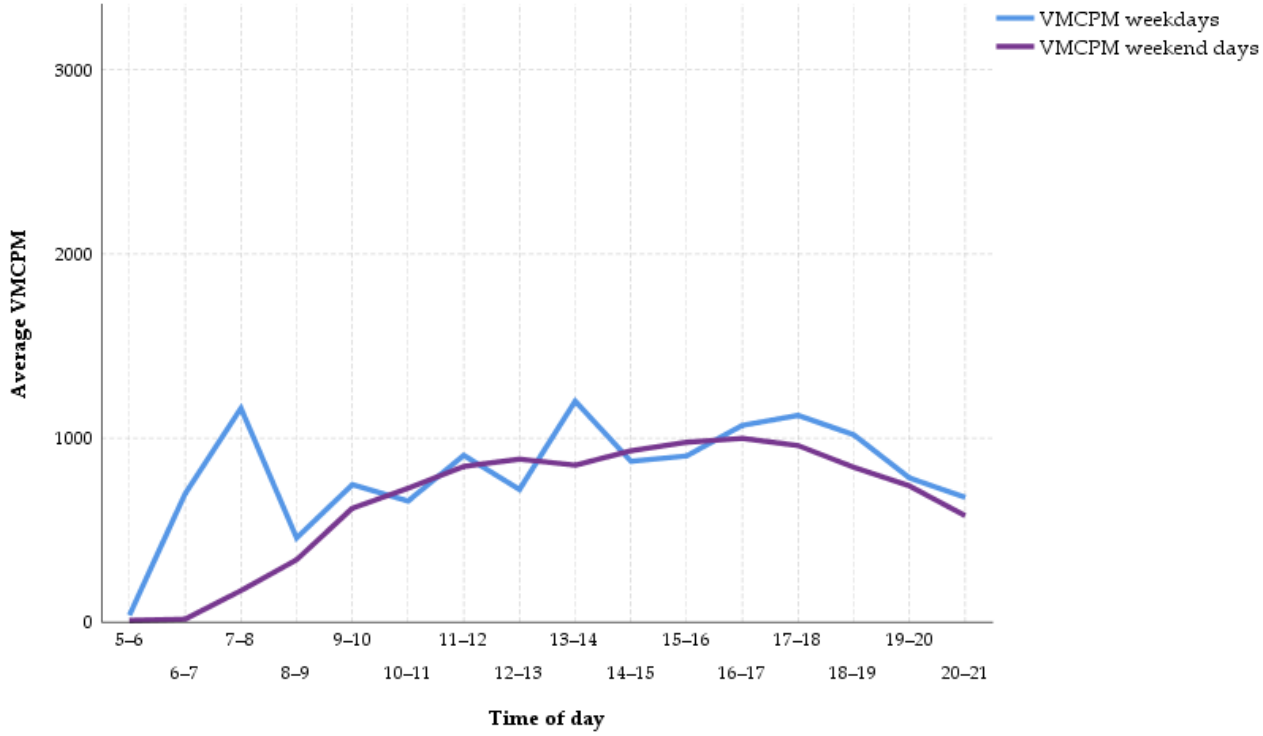

Figure 3. Vector magnitude counts per minute (VMCPM) pattern on weekdays and weekend days.

Whereas SES was not relevant for PA behavior, BMI consistently exhibited significant associations with girls' PA and SB both on weekdays and weekend days. In total, BMI was positively related to ST (r = 0.24, $p < 0.001$) and negatively related to LPA (r = −0.30, $p < 0.001$), MVPA (r = −0.15, $p < 0.05$) and VMCPM (r = −0.25, $p < 0.001$).

4. Discussion

The female sixth-grade students examined in the CReActivity study showed good levels of PA with 90.4% fulfilling the WHO recommendation on a weekday and 57.4% on a weekend day. Healthier PA and SB were significantly related to lower BMI. PA behavior was better than what had been assumed based on previous studies in Germany [15–17]. MVPA values of the present study were also higher compared to the international HELENA study, which reported a daily average of around 50 min of MVPA for adolescent girls from nine European countries including Germany [42]. Accelerometer-measured PA of participants aged 9 to 13 years from the ENERGY project conducted in five European countries indicated clearly lower mean MVPA values of 36 and 25 min on weekdays and weekend days, respectively [43]. However, the MVPA values of the present study were highly similar to those of an international systematic review by Brooke, Corder, Atkin and van Sluijs examining accelerometer-measured PA of school-aged children [21]. In the 36 studies included in their meta-analysis, most of them conducted in Europe and North America, subjects exhibited on average 82.3 min of MVPA on weekdays and 68.3 min of MVPA on weekend days. However, the standard deviation of the means amounts to 44 min, indicating a substantial variance in the MVPA values found by the different studies. The high ST values of more than eight hours in our study fit the results of a study with data from 40 countries in Europe and North America by Hallal and colleagues [44]. They estimated that two thirds of adolescents aged 13 to 15 already gathered at least two hours per day of ST only by watching television. With an average of around nine hours of daily ST accounting for 70% of girls' total wear time, the results of the HELENA study were highly similar to the results presented in our study [42]. The substantial amount of ST in the present study was even exceeded by that reported in the results from female

adolescents included in the Spanish UP&DOWN study, who exhibited more than seven hours of leisure-time SB averaged over weekdays and weekend days [45].

Even though the average PA level during the weekend was above the WHO recommendation in the present study, there was a significant decrease of LPA, MVPA and ST and WT compared to weekdays. The direction and magnitude of the difference in MVPA levels between weekdays and weekend days are in line with the results of the systematic review by Brooke et al. [21], in which MVPA was on average 14 min higher on weekdays than on weekend days. The pooled standardized mean difference of d = 0.42 reflects a small-to-medium effect which is also comparable to the one in our study. Thus, the assumed decline in PA from weekdays to weekend days can be confirmed.

However, the qualitative intensity of PA while being awake and active was only slightly lower on a weekend. Instead, the length of time in which the female adolescents engaged in PA was shorter. The participants of our study exhibited on average about 19 min less MVPA on a weekend day compared to a weekday. Similar to previous studies [21], this difference can mainly be traced back to the commute to and from school. Between 7 a.m. and 8 a.m., adolescents gathered around nine minutes more MVPA on schooldays compared to weekend days. In line with this, WT decreased by two hours from weekdays to weekends because of longer sleep duration in the morning [46]. It seems that students got up on a weekend day at the time they arrive at school on a weekday. This was shown on the curves of the respective activity patterns concerning MVPA and VMCPM, which approximate each other towards 8 a.m. (Figures 2 and 3). As soon as they were awake, the PA pattern on a weekend day was comparable to that on a school day, with the exception of the period between 1 and 2 p.m., which can probably be attributed to the break between morning and afternoon classes or the way back home from school. During this hour, the girls exhibited almost four minutes more MVPA on school days. The remaining difference in MVPA of around six minutes between weekdays and weekend days was spread out during the course of the day. When PA behavior during time segments with different durations is compared, it is recommended to consult a relative measure like VMCPM next to an absolute measure like MVPA [21]. Since the participants averaged two hours more WT on weekdays than on weekend days, the respective difference in VMCPM was examined. Although exhibiting a statistically significant difference in favor of weekdays, the underlying effect was small and without practical meaning as the difference amounted to 20 counts per minute. This result is again supported by the systematic review by Brooke et al., who found a mean difference of about 30 CPM in favor of weekdays [21]. To put this into perspective, the range for LPA in the cut points from Hänggi et al. extends from 180 to 3360 VMCPM, which shows that the detected difference in VMCPM between weekdays and weekend days was, although statistically significant, practically negligible [10]. Additionally, although on weekdays the portion of MVPA during WT was significantly higher and the portion of ST during WT was significantly lower, these differences were small and did not indicate a qualitatively different dimension of PA on weekdays. For example, Figures 2 and 3 illustrate that the intensity of PA which students exhibited between 7 and 8 a.m. on weekdays did not substantially exceed the intensity levels they showed during an average weekend afternoon.

The MVPA level in the examined sample indicates a healthy PA behavior. However, whereas the WHO recommendation [1] regarding PA was on average fulfilled, the German recommendation of 90 min daily MVPA [2] was only reached by a minority of the present sample. Moreover, PA behavior on weekend days was clearly worse than on weekdays. Since the WHO recommendation is understood as a minimum value and because additional health benefits can be expected with higher PA levels [1], the need for sustained PA promotion persists. Additionally, in view of the fact that SB partially implies its own risk factors [7], further drawbacks become apparent. The vast majority of the participants failed to meet the recommendation regarding ST during recreational time [2]. Taking into account that the recommended limit of two hours per day especially refers to avoidable ST, like motorized transport or screen time, the girls tended to approximate this

recommendation on weekdays rather than on weekend days. On average, the students gathered around three hours of ST between 4 and 9 p.m. on a weekday. In the UP&DOWN study, educational-based SB (doing homework, studying and reading) accounted for one third of the girls' leisure-time SB [45]. Thus, by applying these proportions to the SB results presented here, a mentionable proportion of the girls came close to or even fulfilled the ST recommendation when the approximated time spent on having dinner and other necessary activities, like doing homework, was subtracted from their average after-school ST. The average ST on a weekend day of more than seven hours, however, exceeded the recommendation by far. Thus, the assumption that the students did not fulfill the German recommendation regarding ST was largely confirmed, especially for weekend days.

The results indicate that the girls did not spend available time on weekends or after school specifically on being physically active. The increase in MVPA after school compared to school hours was small. Similarly, ST after school was only slightly lower than during school hours. MVPA on a weekend afternoon was nearly the same as during after-school hours. ST on an average weekday afternoon was on the same level as on a weekend day. These findings resemble the results of the HELENA study and two studies conducted in Great Britain with samples comprising similar age groups. In the PEACH study, the portion of MVPA after school was slightly higher than during school hours and during a weekend afternoon. In female participants of the HELENA study and in the PEACH study, the percentage of ST was only slightly lower after school than during school hours. Furthermore, in these samples, as well as for the girls of the SPEEDY study, the portion of ST during after-school hours was on the same level as on a weekend [47–49]. In short, weekday MVPA in the afternoon was not much higher than during school hours, ST did not significantly decrease in the afternoon. A comparison of afternoon PA and SB between weekdays and weekend days exhibited negligible differences. The highly comparable results of the systematic review of Brooke et al. [21] regarding the in-school versus out-of-school comparison and the out-of-school versus weekend comparison led the authors to the similar conclusion that children did not choose to spend their additional free time during weekends on PA. An alternative explanation would be that leisure time hardly exists for students since they spend too much time doing homework in the afternoon and during the weekend [50].

However, even if hardly any free time is available for students, there should still be several ways that PA can be promoted. Given that, during school hours, students' PA was low and ST was high, the school represents one setting where interventions, especially of a multicomponent character, can be effective. One possible component is the promotion of active transport, which has led to an increase in PA in a variety of studies [25] and is also in line with the PA peaks on weekdays in the present sample. Another intervention component promoting PA directly within school hours could be classroom-based interventions implemented in the regular curriculum [26]. Further components of interventions in the school setting could include activity breaks, after-school programs, changes in the school environment and improvements in the quality of PE lessons [25]. One possibility to positively affect PE quality is to conduct PE lessons based on self-determination theory (SDT; [51]). SDT is one of the theoretical frameworks that is commonly used in the educational context [52]. Applied to PE, it may initiate a chain of effects resulting in higher PA levels. SDT suggests that if the three so-called basic psychological needs (BPNs), autonomy, competence and relatedness, are satisfied, autonomous motivation is higher, which finally promotes the respective behavior. Studies in a PE context have shown that PE teachers can satisfy students' BPNs by applying a need-supportive teaching behavior [53]. This way, students' autonomous motivation during PE can be increased [53,54]. Subsequently, autonomous motivation for PA in leisure time can be enhanced as well, which finally results in higher PA levels after school and on weekends [53–55]. In this way, PE can enable a transfer of PA-enhancing effects during school hours into leisure time, and thus the family setting. In this setting, further contributions to PA increase and SB decrease can be made by appealing to the role of the parents. It has been shown that parental support

can increase PA and reduce SB of children [25,56]. Additionally, the PA and screen time of children are positively related to the PA and screen time of their parents [25]. These findings can help build the foundation for interventions in the family setting in order to find appropriate responses to high levels of SB during weekends, which were also found in the present study.

Accelerometer-based PA data assessment is more objective than a self-report approach [9]. However, device-based measurement techniques are not necessarily free of possible biases. One example would be a possible motivational effect of the PA measurement itself, referred to as the mere-measurement effect [57]. The students knew that the accelerometers measured PA and they were also aware of the fact that higher PA levels are socially rewarded. Social desirability and reactivity leading to behavior adaption in the sense of a "Hawthorne effect" may have then led to students trying their best to be physically active [58,59]. This effect might have occurred despite the fact that the students who were enrolled in the intervention study were not told whether they formed part of the intervention or control group, as an increase in PA due to its mere measurement can happen in members of both groups [60].

Additionally, and even more importantly, researchers make many data processing and analysis decisions when creating accelerometer-derived estimates of ST and PA [30,61]. These include decisions concerning the sampling rate, the choice of epoch length, the selection of an algorithm to differentiate accelerometer WT from non-WT and the cut-point definitions to determine the amount of time spent in ST and PA intensity levels. The choice of the methodological procedure was an important factor for explaining the high MVPA values found in this study in comparison to previous studies in Germany and Europe.

Using short epoch lengths leads to a higher resolution of the measurement and therefore increased MVPA values [61]. Analyzing accelerometer data of 7 to 11-year-olds, Banda et al. could show, with the example of the often-applied Evenson et al. cut points [62], that the average MVPA value using a 60-s epoch length was only 67.2% of the value using 1-s epochs. Using other cut points the difference was even more severe (Romanzini [63]: 65.8%; Treuth [64]: 50.1%; Puyau [65]: 47.4%; Mattocks [66]: 39.6%) [61].

Furthermore, even when activity cut points are applied together with the epoch length originally used to validate the respective cut points, MVPA values still differ to a great extent between the cut points. Banda and colleagues showed in their study that when using Romanzini cut points, 107.6 min of MVPA per day were calculated in comparison to between 15.2 and 59.9 of MVPA minutes per day when using the other four activity cut points [61]. However, the obvious effect of different minimum amounts of counts per minute that have to be reached to classify activities as being at least moderate cannot fully explain the differences in the calculated MVPA values. This is when the question of using vertical axis counts or VM counts comes into play. Romanzini et al. offered cut points which were validated using VM counts, whereas the other four cut points only used the counts of the vertical axis. When analyzing PA behavior by VM cut points, ST values are lower and MVPA values are higher compared to using vertical axis counts only [67]. Using VM scores, the precision of the measurement is enhanced as movements in everyday life are more frequently performed in an anterior–posterior and medio-lateral direction than in a vertical direction. Likely because of that, the MVPA estimates of elderly women examined by Keadle et al. using VM cut points were twice as high as when considering vertical axis counts only. This is supported by a study of Migueles et al. showing that the VM activity cut points from Romanzini et al. and Hänggi et al. lead to the highest MVPA estimates compared to other established cut points [68]. These findings lead to the conclusion that PA estimates using VM cut points and vertical axis cut points cannot be directly compared [67].

As the main strength of our study, we followed recent recommendations calling for high resolution and precision in PA data assessment and analysis by sampling with 30 Hz, using a 1-s epoch length and applying the VM activity cut points from Hänggi [30,61]. In contrast, the German GINIplus and IDEFICS studies used 60-s epochs and vertical axis

cut points [15,16]. The German KiGGS study applied VM cut points but only a 15-s epoch length [17,69]. Both the European HELENA study (including data from adolescents of one German city) and the ENERGY project only measured vertical movements and analyzed accelerometer data with an epoch length of 15 s [42,43]. The Spanish UP&DOWN study used both triaxial and uniaxial accelerometers and a 10-s epoch length [45]. The different decisions regarding accelerometer data sampling and processing criteria have undoubtedly contributed to less accurate and thus lower activity estimates in previous German and European studies compared to our results. The data from the HELENA study have now been examined again with different cut-point definitions, including different epoch lengths [70]. Based on data from the exact same sample, fulfillment of the WHO recommendation for MVPA ranged between 5.9% and 37%, according to the applied cut points. In view of these findings, the authors questioned the results of the HELENA study by suggesting that the reported PA levels could have been significantly different if they had used other epoch lengths, which, however, is only one of several processing criteria in accelerometer data analysis. The authors further concluded that inaccuracies in accelerometer analysis could lead to wrong inferences when examining the relationship of PA levels and health outcomes and thereby underlined the importance of precise accelerometer analyses [70].

With regard to SB, the results of our study and those of previous studies do not differ as much as with regard to PA. The German GINIplus and IDEFICS studies indicated a comparable SB [15,16]. ST values of our study are similar to those of the HELENA study [42]. Participants of the ENERGY project exhibited highly similar ST values both on weekdays and on weekend days. Female participants of the Spanish UP&DOWN study exhibited higher SB levels, with more than seven hours of ST during leisure time only [45]. The reason for the higher agreement between studies regarding ST values compared to PA values is that estimation of ST values is less affected by different accelerometer sampling and processing criteria. For example, if a person is sitting still for an uninterrupted period of time, this is considered as ST regardless of the chosen sampling rate, epoch length or activity cut points as there is no activity at all. Different choices in these criteria do not have an effect until the person shows short interruptions of ST by intermittent periods of PA, which may only then be identified as activity if the chosen sampling and analysis criteria allow for it. An intermittent PA behavior is more common among children and adolescents, which underlines the necessity of accelerometer analyses with a high resolution for these populations especially [30].

The main limitation of this study is that the results only refer to female sixth graders and cannot be considered as being representative for the German population of children and adolescents. Analyses with samples including an equal number of female and male participants, as well as participants from different age groups, regions and school types, are necessary to allow for nationwide and precise insights into PA and SB of children and adolescents in Germany. Another limitation of the study is the lack of a log recording the times when the accelerometer was worn or a diary depicting the course of the day of every student. This way, the interpretation of the differences between PA and SB on weekdays and weekend days could have been corroborated by the students' recordings. Furthermore, since data were collected during autumn and winter, data of this study do not reflect the possible seasonal variations in PA and SB. PA of children and adolescents tends to be higher in spring and summer compared to autumn and winter [71,72]. SB normally reaches its highest level during autumn and winter, with seasonal differences being greater on weekends [72]. Whereas this might actually attenuate or even balance the mere-measurement effect discussed above [57], it can certainly be considered as a limitation in terms of the representativeness of the PA and SB data regarding seasonal variations.

5. Conclusions

The results of this study lead to three main conclusions. First of all, PA behavior of the female sixth graders participating in the CReActivity project was better than expected in light of previous German and international studies. The vast majority fulfilled the

WHO guideline on PA on weekdays and more than half of the students were sufficiently active on weekend days. Secondly, SB of the participants was worrying, especially during school hours and on weekend days. Considering that the detrimental effects of high SB on health are partially independent of the effects of physical inactivity, multicomponent interventions need to find solutions that enable students to reduce their SB levels at school and engage in less sedentary activities with family and friends during weekends. Third, the accelerometer assessment of PA and SB would have led to less precise results if the sampling and processing criteria of previous German and international studies had been applied. This questions the accuracy of previous findings and highlights the necessity of larger representative studies that follow the most recent recommendations regarding accelerometer-based measurement of PA and SB. Only highly precise measurements of PA and SB levels and patterns allow for an accurate problem analysis that can subsequently serve as foundation for creating suitable and effective solutions.

Supplementary Materials: The following are available online at https://www.mdpi.com/1660-4601/18/1/32/s1. The dataset analyzed for this study can be found online as supplementary file S1.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the Technical University of Munich (protocol code: 155/16 S; date of approval: 12 May 2016).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available online as supplementary file S1.

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References

1. Bull, F.C.; Al-Ansari, S.S.; Biddle, S.; Borodulin, K.; Buman, M.P.; Cardon, G.; Carty, C.; Chaput, J.-P.; Chastin, S.; Chou, R.; et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br. J. Sports Med.* **2020**, *54*, 1451. [CrossRef] [PubMed]
2. Rütten, A.; Pfeifer, K. *Nationale Empfehlungen für Bewegung und Bewegungsförderung*; Bundeszentrale für gesundheitliche Aufklärung: Köln, Germany, 2017.
3. Janssen, I.; LeBlanc, A.G. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int. J. Behav. Nutr. Phys. Act.* **2010**, *7*, 40. [CrossRef] [PubMed]
4. Poitras, V.J.; Gray, C.E.; Borghese, M.M.; Carson, V.; Chaput, J.P.; Janssen, I.; Katzmarzyk, P.T.; Pate, R.R.; Connor Gorber, S.; Kho, M.E.; et al. Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Appl. Physiol. Nutr. Metab.* **2016**, *41*, S197–S239. [CrossRef] [PubMed]
5. Tremblay, M.S.; Aubert, S.; Barnes, J.D.; Saunders, T.J.; Carson, V.; Latimer-Cheung, A.E.; Chastin, S.F.M.; Altenburg, T.M.; Chinapaw, M.J.M.; Altenburg, T.M.; et al. Sedentary Behavior Research Network (SBRN)—Terminology Consensus Project process and outcome. *Int. J. Behav. Nutr. Phys. Act.* **2017**, *14*, 75. [CrossRef] [PubMed]

6. Tremblay, M.S.; LeBlanc, A.G.; Janssen, I.; Kho, M.E.; Hicks, A.; Murumets, K.; Colley, R.C.; Duggan, M. Canadian sedentary behaviour guidelines for children and youth. *Appl. Physiol. Nutr. Metab.* **2011**, *36*, 59–64. [CrossRef] [PubMed]
7. van der Ploeg, H.P.; Hillsdon, M. Is sedentary behaviour just physical inactivity by another name? *Int. J. Behav. Nutr. Phys. Act.* **2017**, *14*, 142. [CrossRef]
8. Carson, V.; Hunter, S.; Kuzik, N.; Gray, C.E.; Poitras, V.J.; Chaput, J.P.; Saunders, T.J.; Katzmarzyk, P.T.; Okely, A.D.; Connor Gorber, S.; et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth: An update. *Appl. Physiol. Nutr. Metab.* **2016**, *41*, S240–S265. [CrossRef]
9. Loprinzi, P.D.; Cardinal, B.J. Measuring children's physical activity and sedentary behaviors. *J. Exerc. Sci. Fit.* **2011**, *9*, 15–23. [CrossRef]
10. Hänggi, J.M.; Phillips, L.R.; Rowlands, A.V. Validation of the GT3X ActiGraph in children and comparison with the GT1M ActiGraph. *J. Sci. Med. Sport* **2013**, *16*, 40–44. [CrossRef]
11. Sherar, L.B.; Griew, P.; Esliger, D.W.; Cooper, A.R.; Ekelund, U.; Judge, K.; Riddoch, C. International Children's Accelerometry Database (ICAD): Design and methods. *BMC Public Health* **2011**, *11*, 485. [CrossRef]
12. Demetriou, Y.; Hebestreit, A.; Reimers, A.K.; Schlund, A.; Niessner, C.; Schmidt, S.; Finger, J.D.; Mutz, M.; Völker, K.; Vogt, L.; et al. Results from Germany's 2018 report card on physical activity for children and youth. *J. Phys. Act. Health* **2018**, *15*, S363–S365. [CrossRef]
13. Finger, J.D.; Varnaccia, G.; Borrmann, A.; Lange, C.; Mensink, G. Körperliche Aktivität von Kindern und Jugendlichen in Deutschland—Querschnittergebnisse aus KiGGS Welle 2 und Trends. *J. Health Monit.* **2018**, *3*, 24–31. [CrossRef]
14. Bucksch, J.; Inchley, J.; Hamrik, Z.; Finne, E.; Kolip, P.; the HBSC Study Group Germany. Trends in television time, non-gaming PC use and moderate-to-vigorous physical activity among German adolescents 2002–2010. *BMC Public Health* **2014**, *14*, 351. [CrossRef] [PubMed]
15. Konstabel, K.; Veidebaum, T.; Verbestel, V.; Moreno, L.A.; Bammann, K.; Tornaritis, M.; Eiben, G.; Molnar, D.; Siani, A.; Sprengeler, O.; et al. Objectively measured physical activity in European children: The IDEFICS study. *Int. J. Obes. (Lond.)* **2014**, *38* (Suppl. 2), S135–S143. [CrossRef] [PubMed]
16. Pfitzner, R.; Gorzelniak, L.; Heinrich, J.; von Berg, A.; Klümper, C.; Bauer, C.P.; Koletzko, S.; Berdel, D.; Horsch, A.; Schulz, H. Physical activity in German adolescents measured by accelerometry and activity diary: Introducing a comprehensive approach for data management and preliminary results. *PLoS ONE* **2013**, *8*, e65192. [CrossRef] [PubMed]
17. Woll, A.; Oriwol, D.; Anedda, B.; Burchartz, A.; Hanssen-Doose, A.; Kopp, M.; Niessner, C.; Schmidt, S.; Bös, K.; Worth, A. *Körperliche Aktivität, Motorische Leistungsfähigkeit und Gesundheit in Deutschland: Ergebnisse aus der Motorik-Modul-Längsschnittstudie (MoMo)*; Karlsruher Institut für Technologie (KIT): Karlsruhe, Germany, 2019.
18. Cooper, A.; Goodman, A.; Page, A.; Sherar, L.; Esliger, D.; Sluijs, E.; Andersen, L.; Anderssen, S.; Cardon, G.; Davey, R.; et al. Objectively measured physical activity and sedentary time in youth: The International children's accelerometry database (ICAD). *Int. J. Behav. Nutr. Phys. Act.* **2015**, *12*, 113. [CrossRef] [PubMed]
19. Manz, K.; Schlack, R.; Poethko-Müller, C.; Mensink, G.; Finger, J.; Lampert, T. Körperlich-sportliche Aktivität und Nutzung elektronischer Medien im Kindes- und Jugendalter. In *Bundesgesundheitsblatt—Gesundheitsforschung—Gesundheitsschutz*; Robert Koch-Institut, Epidemiologie und Gesundheitsberichterstattung: Berlin, Germany, 2014; Volume 57.
20. Huber, G.; Köppel, M. Analysis of sedentary times of children and adolescents between 4 and 20 years. *Dtsch. Z. Sportmed.* **2017**, *67*, 101–106. [CrossRef]
21. Brooke, H.L.; Corder, K.; Atkin, A.J.; van Sluijs, E.M. A systematic literature review with meta-analyses of within- and between-day differences in objectively measured physical activity in school-aged children. *Sports Med. (Auckl.)* **2014**, *44*, 1427–1438. [CrossRef] [PubMed]
22. Aznar, S.; Naylor, P.J.; Silva, P.; Pérez, M.; Angulo, T.; Laguna, M.; Lara, M.T.; López-Chicharro, J. Patterns of physical activity in Spanish children: A descriptive pilot study. *Child Care Health Dev.* **2011**, *37*, 322–328. [CrossRef]
23. Rhodes, R.E.; McEwan, D.; Rebar, A.L. Theories of physical activity behaviour change: A history and synthesis of approaches. *Psychol. Sport. Exerc.* **2019**, *42*, 100–109. [CrossRef]
24. Parajára, M.d.C.; de Castro, B.M.; Coelho, D.B.; Meireles, A.L. Are neighborhood characteristics associated with sedentary behavior in adolescents? A systematic review. *Int. J. Environ. Health Res.* **2020**, *30*, 388–408. [CrossRef] [PubMed]
25. Messing, S.; Rütten, A.; Abu-Omar, K.; Ungerer-Röhrich, U.; Goodwin, L.; Burlacu, I.; Gediga, G. How can physical activity be promoted among children and adolescents? A systematic review of reviews across settings. *Front. Public Health* **2019**, *7*, 55. [CrossRef] [PubMed]
26. Innerd, A.L.; Azevedo, L.B.; Batterham, A.M. The effect of a curriculum-based physical activity intervention on accelerometer-assessed physical activity in schoolchildren: A non-randomised mixed methods controlled before-and-after study. *PLoS ONE* **2019**, *14*, e0225997. [CrossRef] [PubMed]
27. Parrish, A.-M.; Okely, A.D.; Stanley, R.M.; Ridgers, N.D. The effect of school recess interventions on physical activity. *Sports Med.* **2013**, *43*, 287–299. [CrossRef]
28. Larouche, R.; Mammen, G.; Rowe, D.A.; Faulkner, G. Effectiveness of active school transport interventions: A systematic review and update. *BMC Public Health* **2018**, *18*, 206. [CrossRef]
29. Demetriou, Y.; Gillison, F.; McKenzie, T. After-school physical activity interventions on child and adolescent physical activity and health: A review of reviews. *Adv. Phys. Educ.* **2017**, *7*, 191–215. [CrossRef]

30. Migueles, J.H.; Cadenas-Sanchez, C.; Ekelund, U.; Delisle Nystrom, C.; Mora-Gonzalez, J.; Lof, M.; Labayen, I.; Ruiz, J.R.; Ortega, F.B. Accelerometer data collection and processing criteria to assess physical activity and other outcomes: A systematic review and practical considerations. *Sports Med. (Auckl.)* **2017**, *47*, 1821–1845. [CrossRef]
31. Demetriou, Y.; Bachner, J. A school-based intervention based on self-determination theory to promote girls' physical activity: Study protocol of the CReActivity cluster randomised controlled trial. *BMC Public Health* **2019**, *19*, 519. [CrossRef]
32. Nold, D. Sozioökonomischer Status von Schülerinnen und Schülern 2008. Ergebnisse des Mikrozensus. *Wirtsch. Stat.* **2010**, *2*, 138–149.
33. Rutterford, C.; Copas, A.; Eldridge, S. Methods for sample size determination in cluster randomized trials. *Int. J. Epidemiol.* **2015**, *44*, 1051–1067. [CrossRef]
34. Ganzeboom, H. A new International Socio-Economic Index (ISEI) of occupational status for the International Standard Classification of Occupation 2008 (ISCO-08) constructed with data from the ISSP 2002–2007. In Proceedings of the Annual Conference of International Social Survey Programme, Lisbon, Portugal, 5 January 2010.
35. Ried-Larsen, M.; Brønd, J.C.; Brage, S.; Hansen, B.H.; Grydeland, M.; Andersen, L.B.; Møller, N.C. Mechanical and free-living comparisons of four generations of the Actigraph activity monitor. *Int. J. Behav. Nutr. Phys. Act.* **2012**, *9*, 113. [CrossRef] [PubMed]
36. Tudor-Locke, C.; Barreira, T.V.; Schuna, J.M.; Mire, E.F.; Chaput, J.-P.; Fogelholm, M.; Hu, G.; Kuriyan, R.; Kurpad, A.; Lambert, E.V.; et al. Improving wear time compliance with a 24-hour waist-worn accelerometer protocol in the International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE). *Int. J. Behav. Nutr. Phys. Act.* **2015**, *12*, 11. [CrossRef] [PubMed]
37. Aibar, A.; Bois, J.E.; Zaragoza, J.; Generelo, E.; Julian, J.A.; Paillard, T. Do epoch lengths affect adolescents' compliance with physical activity guidelines? *J. Sports Med. Phys. Fit.* **2014**, *54*, 326–334.
38. Howe, C.A.; Staudenmayer, J.W.; Freedson, P.S. Accelerometer prediction of energy expenditure: Vector magnitude versus vertical axis. *Med. Sci. Sports Exerc.* **2009**, *41*, 2199–2206. [CrossRef]
39. Choi, L.; Liu, Z.; Matthews, C.E.; Buchowski, M.S. Validation of accelerometer wear and nonwear time classification algorithm. *Med. Sci. Sports Exerc.* **2011**, *43*, 357–364. [CrossRef]
40. IBM Corporation. *IBM SPSS Statistics for Windows*; 25.0; IBM Corporation: Armonk, NY, USA, 2017.
41. Cohen, J. A power primer. *Psychol. Bull.* **1992**, *112*, 155–159. [CrossRef]
42. Ruiz, J.R.; Ortega, F.B.; Martínez-Gómez, D.; Labayen, I.; Moreno, L.A.; De Bourdeaudhuij, I.; Manios, Y.; Gonzalez-Gross, M.; Mauro, B.; Molnar, D.; et al. Objectively measured physical activity and sedentary time in European adolescents: The HELENA study. *Am. J. Epidemiol.* **2011**, *174*, 173–184. [CrossRef]
43. Chinapaw, M.J.M.; de Niet, M.; Verloigne, M.; De Bourdeaudhuij, I.; Brug, J.; Altenburg, T.M. from sedentary time to sedentary patterns: Accelerometer data reduction decisions in youth. *PLoS ONE* **2014**, *9*, e111205. [CrossRef]
44. Hallal, P.C.; Andersen, L.B.; Bull, F.C.; Guthold, R.; Haskell, W.; Ekelund, U. Global physical activity levels: Surveillance progress, pitfalls, and prospects. *Lancet* **2012**, *380*, 247–257. [CrossRef]
45. Cabanas-Sánchez, V.; García-Cervantes, L.; Esteban-Gonzalo, L.; Girela-Rejón, M.J.; Castro-Piñero, J.; Veiga, Ó.L. Social correlates of sedentary behavior in young people: The UP&DOWN study. *J. Sport Health Sci.* **2020**, *9*, 189–196. [CrossRef]
46. Hasler, B.P.; Dahl, R.E.; Holm, S.M.; Jakubcak, J.L.; Ryan, N.D.; Silk, J.S.; Phillips, M.L.; Forbes, E.E. Weekend-weekday advances in sleep timing are associated with altered reward-related brain function in healthy adolescents. *Biol. Psychol.* **2012**, *91*, 334–341. [CrossRef]
47. Atkin, A.J.; Foley, L.; Corder, K.; Ekelund, U.; van Sluijs, E.M. Determinants of three-year change in children's objectively measured sedentary time. *PLoS ONE* **2016**, *11*, e0167826. [CrossRef] [PubMed]
48. Grao-Cruces, A.; Sánchez-Oliva, D.; Padilla-Moledo, C.; Izquierdo-Gómez, R.; Cabanas-Sánchez, V.; Castro-Piñero, J. Changes in the school and non-school sedentary time in youth: The UP&DOWN longitudinal study. *J. Sports Sci.* **2020**, *38*, 780–786. [CrossRef] [PubMed]
49. Harding, S.K.; Page, A.S.; Falconer, C.; Cooper, A.R. Longitudinal changes in sedentary time and physical activity during adolescence. *Int. J. Behav. Nutr. Phys. Act.* **2015**, *12*, 44. [CrossRef] [PubMed]
50. Börner, N.; Conraths, A.; Gerken, U.; Steinhauer, R.; Stötzel, J.; Tabel, A. *Bildungsbericht Ganztagsschule NRW 2014*; Technische Universität Dortmund: Dortmund, Germany, 2014.
51. Ryan, R.M.; Deci, E.L. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *Am. Psychol.* **2000**, *55*, 68–78. [CrossRef] [PubMed]
52. Vaquero-Solís, M.; Gallego, D.I.; Tapia-Serrano, M.; Pulido, J.J.; Sánchez-Miguel, P.A. School-based physical activity interventions in children and adolescents: A systematic review. *Int. J. Environ. Res. Public Health* **2020**, *17*, 999. [CrossRef] [PubMed]
53. Standage, M.; Gillison, F.B.; Ntoumanis, N.; Treasure, D.C. Predicting students' physical activity and health-related well-being: A prospective cross-domain investigation of motivation across school physical education and exercise settings. *J. Sport Exerc. Psychol.* **2012**, *34*, 37–60. [CrossRef] [PubMed]
54. Chatzisarantis, N.L.; Hagger, M.S. Effects of an intervention based on self-determination theory on self-reported leisure-time physical activity participation. *Psychol. Health* **2009**, *24*, 29–48. [CrossRef]
55. McDavid, L.; Cox, A.E.; McDonough, M.H. Need fulfillment and motivation in physical education predict trajectories of change in leisure-time physical activity in early adolescence. *Psychol. Sport Exerc.* **2014**, *15*, 471–480. [CrossRef]
56. Laird, Y.; Fawkner, S.; Kelly, P.; McNamee, L.; Niven, A. The role of social support on physical activity behaviour in adolescent girls: A systematic review and meta-analysis. *Int. J. Behav. Nutr. Phys. Act.* **2016**, *13*, 79. [CrossRef]

57. Rodrigues, A.M.; O'Brien, N.; French, D.P.; Glidewell, L.; Sniehotta, F.F. The question-behavior effect: Genuine effect or spurious phenomenon? A systematic review of randomized controlled trials with meta-analyses. *Health Psychol.* **2015**, *34*, 61–78. [CrossRef] [PubMed]
58. Dössegger, A.; Ruch, N.; Jimmy, G.; Braun-Fahrländer, C.; Mäder, U.; Hänggi, J.; Hofmann, H.; Puder, J.J.; Kriemler, S.; Bringolf-Isler, B. Reactivity to accelerometer measurement of children and adolescents. *Med. Sci. Sports Exerc.* **2014**, *46*, 1140–1146. [CrossRef] [PubMed]
59. Wickström, G.; Bendix, T. The "Hawthorne effect"—What did the original Hawthorne studies actually show? *Scand. J. Work Environ. Health* **2000**, *26*, 363–367. [CrossRef] [PubMed]
60. Waters, L.; Reeves, M.; Fjeldsoe, B.; Eakin, E. Control group improvements in physical activity intervention trials and possible explanatory factors: A systematic review. *J. Phys. Act. Health* **2012**, *9*, 884–895. [CrossRef] [PubMed]
61. Banda, J.A.; Haydel, K.F.; Davila, T.; Desai, M.; Bryson, S.; Haskell, W.L.; Matheson, D.; Robinson, T.N. Effects of varying epoch lengths, wear time algorithms, and activity cut-points on estimates of child sedentary behavior and physical activity from accelerometer data. *PLoS ONE* **2016**, *11*, e0150534. [CrossRef]
62. Evenson, K.R.; Catellier, D.J.; Gill, K.; Ondrak, K.S.; McMurray, R.G. Calibration of two objective measures of physical activity for children. *J. Sports Sci.* **2008**, *26*, 1557–1565. [CrossRef]
63. Romanzini, M.; Petroski, E.L.; Ohara, D.; Dourado, A.C.; Reichert, F.F. Calibration of ActiGraph GT3X, Actical and RT3 accelerometers in adolescents. *Eur. J. Sport Sci.* **2014**, *14*, 91–99. [CrossRef]
64. Treuth, M.S.; Schmitz, K.; Catellier, D.J.; McMurray, R.G.; Murray, D.M.; Almeida, M.J.; Going, S.; Norman, J.E.; Pate, R. Defining accelerometer thresholds for activity intensities in adolescent girls. *Med. Sci. Sports Exerc.* **2004**, *36*, 1259–1266.
65. Puyau, M.R.; Adolph, A.L.; Vohra, F.A.; Butte, N.F. Validation and calibration of physical activity monitors in children. *Obes. Res.* **2002**, *10*, 150–157. [CrossRef]
66. Mattocks, C.; Leary, S.; Ness, A.; Deere, K.; Saunders, J.; Tilling, K.; Kirkby, J.; Blair, S.N.; Riddoch, C. Calibration of an accelerometer during free-living activities in children. *Int. J. Pediatr. Obes.* **2007**, *2*, 218–226. [CrossRef]
67. Keadle, S.K.; Shiroma, E.J.; Freedson, P.S.; Lee, I.M. Impact of accelerometer data processing decisions on the sample size, wear time and physical activity level of a large cohort study. *BMC Public Health* **2014**, *14*, 1210. [CrossRef] [PubMed]
68. Migueles, J.H.; Cadenas-Sanchez, C.; Tudor-Locke, C.; Löf, M.; Esteban-Cornejo, I.; Molina-Garcia, P.; Mora-Gonzalez, J.; Rodriguez-Ayllon, M.; Garcia-Marmol, E.; Ekelund, U.; et al. Comparability of published cut-points for the assessment of physical activity: Implications for data harmonization. *Scand. J. Med. Sci. Sports* **2019**, *29*, 566–574. [CrossRef] [PubMed]
69. Burchartz, A.; Manz, K.; Anedda, B.; Niessner, C.; Oriwol, D.; Schmidt, S.C.; Woll, A. Measurement of physical activity and sedentary behavior by accelerometry among a nationwide sample from the KiGGS and MoMo study: Study protocol. *JMIR Res. Protoc.* **2020**, *9*, e14370. [CrossRef] [PubMed]
70. Vanhelst, J.; Béghin, L.; Salleron, J.; Ruiz, J.R.; Ortega, F.B.; Ottevaere, C.; Molnar, D.; Kafatos, A.; Manios, Y.; Widhalm, K.; et al. Impact of the choice of threshold on physical activity patterns in free living conditions among adolescents measured using a uniaxial accelerometer: The HELENA study. *J. Sports Sci.* **2014**, *32*, 110–115. [CrossRef] [PubMed]
71. Rich, C.; Griffiths, L.J.; Dezateux, C. Seasonal variation in accelerometer-determined sedentary behaviour and physical activity in children: A review. *Int. J. Behav. Nutr. Phys. Act.* **2012**, *9*, 49. [CrossRef]
72. Atkin, A.J.; Sharp, S.J.; Harrison, F.; Brage, S.; Van Sluijs, E.M.F. Seasonal variation in children's physical activity and sedentary time. *Med. Sci. Sports Exerc.* **2016**, *48*, 449–456. [CrossRef]

3.2 Article 2

Authors: Joachim Bachner, David J. Sturm, Xavier García-Massó, Javier Molina-García, & Yolanda Demetriou

Title: Physical Activity-Related Profiles of Female Sixth-Graders Regarding Motivational Psychosocial Variables: A Cluster Analysis Within the CReActivity Project

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Summary:

Only a small minority of studies in the field of PA research uses a person-oriented approach in analyzing the determinants of interindividual differences in PA behaviour. By means of the traditionally applied variable-based approach, possible coexistences and interactions of different determinants within a given person cannot be examined. Therefore, the aim of the second article was to apply a person-oriented approach on the psychosocial determinants assessed in the CReActivity project, to examine a) which profiles regarding PA-related psychosocial variables typically occur in female sixth-graders, (b) if these profiles deliver a self-consistent picture according to theoretical assumptions, and (c) if the profiles also contribute to the explanation of interindividual differences in PA. The sample for this study comprised 475 female sixth-graders. Results of a self-organizing maps analysis suggested the extraction of three superordinate profiles, representing one positive, one medium and one negative cluster in terms of their PA-related psychosocial resources. The superordinate cluster solution represented a self-consistent picture that was in line with theoretical assumptions. Furthermore, the identified profiles contributed to the explanation of PA behaviour, with the positive cluster accumulating an average of six minutes more MVPA per day than the medium cluster and ten minutes more than the negative cluster. Additionally, via the graphic presentation of the results, a subgroup within the positive cluster was detected, whose shape differed to some extent from the superordinate profile. Members of this subordinate profile were the most active, since they benefited from a specific combination of intrinsic and external regulations with regard to PA.

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Contribution:

Joachim Bachner was the leading author of the article. Yolanda Demetriou and Joachim Bachner engaged in acquisition of funding. Javier Molina-García, Xavier García-Massó and Joachim Bachner developed the idea for the study. David J. Sturm and Joachim Bachner collected the data. Joachim Bachner and Xavier García-Massó developed the study design and analyzed the data. Joachim Bachner wrote the article. His co-authors contributed to manuscript revision. Javier Molina-García and Yolanda Demetriou supervised the cooperation.

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Physical Activity-Related Profiles of Female Sixth-Graders Regarding Motivational Psychosocial Variables: A Cluster Analysis Within the CReActivity Project

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Introduction: Adolescents' physical activity (PA) behavior can be driven by several psychosocial determinants at the same time. Most analyses use a variable-based approach that examines relations between PA-related determinants and PA behavior on the between-person level. Using this approach, possible coexistences of different psychosocial determinants within one person cannot be examined. Therefore, by applying a person-oriented approach, this study examined (a) which profiles regarding PA-related psychosocial variables typically occur in female sixth-graders, (b) if these profiles deliver a self-consistent picture according to theoretical assumptions, and (c) if the profiles contribute to the explanation of PA.

Materials and Methods: The sample comprised 475 female sixth-graders. Seventeen PA-related variables were assessed: support for autonomy, competence and relatedness in PE as well as their satisfaction in PE and leisure-time; behavioral regulation of exercise (five subscales); self-efficacy and social support from friends and family (two subscales). Moderate-to-vigorous PA was measured using accelerometers. Data were analyzed using the self-organizing maps (SOM) analysis, a cluster analysis including an unsupervised algorithm for non-linear models.

Results: According to the respective level of psychosocial resources, a positive, a medium and a negative cluster were identified. This superordinate cluster solution represented a self-consistent picture that was in line with theoretical assumptions. The three-cluster solution contributed to the explanation of PA behavior, with the positive cluster accumulating an average of 6 min more moderate-to-vigorous PA per day than the medium cluster and 10 min more than the negative cluster. Additionally, SOM detected a subgroup within the positive cluster that benefited from a specific combination of intrinsic and external regulations with regard to PA.

Discussion: The results underline the relevance of the assessed psychosocial determinants of PA behavior in female sixth-graders. The results further indicate that the different psychosocial resources within a given person do not develop independently of one another, which supports the use of a person-oriented approach. In addition, the SOM analysis identified subgroups with specific characteristics, which would have remained undetected using variable-based approaches. Thus, this approach offers the possibility to reduce data complexity without overlooking subgroups with special demands that go beyond the superordinate cluster solution.

Keywords: self-organizing maps analysis, person-oriented approach, cluster analysis, accelerometer, basic psychological needs, physical activity, physical education

INTRODUCTION

Regular physical activity (PA) is an important component of a healthy lifestyle. Engaging in regular PA helps to prevent overweight and obesity and lowers the risk of diseases like diabetes mellitus type II, colon and breast cancers or cardiovascular as well as mental diseases (McKinney et al., 2016; Granger et al., 2017). The World Health Organization (WHO) recommends children and adolescents to engage in at least 60 min of moderate-to-vigorous physical activity (MVPA) per day (World Health Organization [WHO], 2018). Children's compliance with the WHO guideline is crucial because the participation in regular PA not only leads to positive short- and middle-term effects on their health, but also increases the probability of an active and healthy lifestyle later in adulthood (Hallal et al., 2006; Telama, 2009). However, only a minority of children and adolescents fulfill the minimum guideline of MVPA. Pooled analyses of self-report studies have shown that worldwide 19.7% of children aged 13 to 15 years and 19% of students aged 11 to 17 years reach 60 min of daily MVPA (Hallal et al., 2012; Guthold et al., 2020). Analysis of accelerometer data of over 26,000 5-17-year olds from ten countries indicated an even lower rate with 9% of boys and 1.9% of girls fulfilling the WHO guideline (Cooper et al., 2015). In addition to this gender effect, which is consistently found during adolescence, PA decreases with age (Dumith et al., 2011; Van Hecke et al., 2016). Furthermore, although there have been ambiguous findings, a lower socioeconomic status (SES) of the household tends to have a negative effect on PA levels in children and adolescents (Sallis et al., 2000; Corder et al., 2011; Molina-García et al., 2017; Finger et al., 2018).

By means of an intervention program in physical education (PE), the CReActivity project (Demetriou and Bachner, 2019) aims to promote PA of female sixth-graders attending lower-track secondary schools. The sample was chosen because it represents a specific risk group regarding physical inactivity in terms of age, gender and socioeconomic status (e.g., Van Hecke et al., 2016; Finger et al., 2018). Thirty-three classes and their respective PE teacher participated in the project and were randomly assigned to intervention group (IG) and control group (CG). While the PE teacher behavior remained unaffected in the CG, PE teachers of the IG were provided with 48 fully elaborated lesson plans specifically designed to support students' basic psychological needs (BPNs) autonomy, competence and relatedness. The lesson plans were divided into the learning domains of football, basketball, gymnastics, health and fitness, swimming and dancing. IG teachers could freely choose which lessons they wanted to implement during the 16-week intervention period. Further details about the intervention program can be found elsewhere (Demetriou and Bachner, 2019).

Self-determination theory (SDT; Ryan and Deci, 2000) and, more specifically, the associated BPN theory (Deci and Ryan, 2000) were chosen as the main foundation for the intervention because they not only allow for the explanation and prediction of human behavior but also include specific mechanisms and instructions on how to actually promote PA behavior via an increase in motivation (Buchan et al., 2012). SDT focuses both on the quantity and on the type of motivation through which human behavior is regulated. According to SDT, six types of motivation can be differentiated and their respective regulation is arranged on a continuum of self-determination (Ryan and Deci, 2000). The state when a person totally lacks motivation is referred to as amotivation. The least autonomous form of motivation is external motivation, when behavior is regulated by external factors such as rewards or imminent penalties. Next on the self-determination continuum is introjected motivation. Introjection describes the circumstance when people are led by external motivation that has already been internalized to some extent. Thus, the behavior does not fully emanate from oneself, but is executed in order to avoid having a bad conscience, to gain pride, or to maintain one's self-esteem. When a person shows a certain behavior because it is personally valued and considered important, it is referred to as identified motivation. Integrated and intrinsic motivation, finally, are the two most autonomous forms of behavioral regulation. They differ in that intrinsic motivation triggers behavior with the purpose of enjoying the respective activity, whereas integrated motivation means that the person has fully integrated the value of the behavior but still strives for a specific outcome apart from having fun (Ryan and Deci, 2000). SDT proclaims that the satisfaction of the so-called BPN autonomy, competence and relatedness leads to autonomous forms of motivation. Autonomous motivation should in turn promote the respective behavior. A systematic review and meta-analysis (Owen et al., 2014) of cross-sectional studies referring to the relationship of autonomous motivation and PA supports this assumption.

Furthermore, several longitudinal studies in the context of physical education (PE) illustrate possible ways to promote PA based on SDT (e.g., Chatzisarantis and Hagger, 2009; Standage et al., 2012; Van den Berghe et al., 2012; McDavid et al., 2014). As a first step, by means of need-supportive teaching behavior in PE classes, the actual satisfaction of BPN can be improved significantly (Standage et al., 2012). Secondly, higher satisfaction of BPN during PE can lead to higher autonomous motivation of students during class (Chatzisarantis and Hagger, 2009; Jaakkola et al., 2012; Standage et al., 2012). Subsequently, autonomous participation in PA during leisure-time (LT) is increased as well, which finally leads to higher PA levels (Chatzisarantis and Hagger, 2009; Standage et al., 2012; McDavid et al., 2014).

To allow for a manipulation check of the CReActivity intervention, the degree of BPN support was assessed. To evaluate the intervention effect, MVPA was measured with accelerometers. To be able to examine possible mediating forces of the intervention effect, BPN satisfaction in PE and leisure-time as well as the quantity and quality of PA-related motivation were assessed. In addition, self-efficacy and social support by family and friends were also measured (Demetriou and Bachner, 2019). As the central construct of the social-cognitive theory (SCT), Bandura defined self-efficacy as "beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments" (1997, p. 3). Although often deemed redundant to competence, self-efficacy was included as a potential mediator with incremental value because competence and self-efficacy can be distinguished both conceptually and statistically (Rodgers et al., 2014). Several reviews consistently identified self-efficacy as a highly relevant psychological correlate and determinant of PA behavior of children and adolescents (Bauman et al., 2012; Cortis et al., 2017). Further reviews concluded that self-efficacy can help to attenuate the decrease in PA during adolescence and can act as the most powerful mediator in intervention studies trying to promote PA (Lubans et al., 2008; van Stralen et al., 2011). Social support by family and friends was considered as a potential mediator because IG students were supposed to take over a teaching role after school and instruct their friends and families to repeat what they had learned in PE. This way, people around the participants were expected to be affected by the intervention as well, which should finally lead to mutual support. Concrete social support on active lifestyles from parents and peers are independent factors affecting children's and adolescents' PA behavior. Several systematic reviews (Mendonça et al., 2014; Laird et al., 2016) indicate the stable and positive association between social support and PA. Specific providers of social support such as family, parents, or friends have been distinguished and their relevance regarding adolescent PA levels has been demonstrated. While peers seem to have an influence during both childhood and adolescence, the effect of parental support on PA tends to decrease as their children reach the age of 16 (Bush and MacDonald, 2015).

Thus, a substantial number of PA-related psychosocial constructs, which in its entirety is also represented in the Youth Physical Activity Promotion Model (Welk, 1999) and other theoretical works (e.g., Laird et al., 2018), was assessed in the CReActivity project. Only with a wide range of psychosocial information available, the idea that PA behavior of an individual is driven by several psychosocial determinants simultaneously could be met and tested. Although this idea had been suggested by the YPAPM (Welk, 1999) and other theoretical models and assumptions (Deci and Ryan, 2000; Vallerand, 2007; Teixeira et al., 2012; Vansteenkiste and Mouratidis, 2016), and had been supported by empirical PA-related studies (Lindwall et al., 2017; Emm-Collison et al., 2020), the majority of studies has applied the traditional variable-based approach (Bergman and Andersson, 2010) that examines relations between different PA-related determinants and PA behavior on the between-person level. Using this approach, the typically occurring coexistence and possible interactions of different psychosocial determinants within one person cannot be examined. Thus, by applying a person-oriented approach to the baseline measures of the CReActivity project, the following research question 1 was examined: Which profiles regarding the assessed PA-related psychosocial variables typically occur in female sixth-graders? If the profiles deliver a self-consistent picture according theoretical assumptions, this would also strengthen the theoretical foundations of the study and would serve as a double-check regarding the validity of the used scales. Therefore, the second research question was posed: Is the coexistence of the psychosocial constructs within the respective profiles in line with theoretical assumptions? Finally, only if the chosen variables lead to profiles that allow for a differentiation between students with different MVPA levels and thus prove to be relevant for PA in this specific sample, the variables can be seen as promising mediators of a subsequent intervention trying to promote MVPA in this sample. Thus, the third research question is: Do the profiles contribute to the explanation of different baseline MVPA levels? To date, this is the first study to examine the relationship between profiles comprising PA-related psychosocial resources and device-based measured MVPA in an adolescent sample. The three research questions led to one central hypothesis. It was assumed that students who have higher MVPA levels, exhibit higher values in BPN support in PE and BPN satisfaction in PE and LT, show a motivation for PA that is rather autonomously regulated, and have higher values in self-efficacy and social support from friends and family.

An appropriate method to examine these questions, given a multitude of variables, is the self-organizing maps (SOM) analysis (Kohonen, 1995). As a cluster analysis, it represents a person-oriented approach, which assumes that various factors used to describe a person, do not develop independently of one another (Bergman and Lundh, 2015). SOM analysis is considered as the predestined method as it provides a number of advantages specifically useful for this study (Herrero-Herrero et al., 2017). First, it includes an unsupervised algorithm for a potentially non-linear data structure. Second, its statistical power is independent from the number of variables included in the analysis. Third, it is a powerful tool to present results in visualized and ostensive form, which quickly illustrates how a complex number of variables are typically associated within a given person. Fourth, by creating superordinate clusters, typical profiles of female adolescents regarding BPN support and satisfaction, motivation, self-efficacy and social support are described and their relevance regarding

MVPA can be examined. Fifth, SOM analyses tend to have a higher accuracy in establishing typical profiles compared to more regularly used clustering techniques (Astel et al., 2007; Budayan et al., 2009; Melo Riveros et al., 2019). Lastly, in addition to the superordinate cluster solution, SOM results may instantly hint toward specific subgroups that, to some extent, stand out of their actual cluster and may show special characteristics and needs.

MATERIALS AND METHODS

Participants

The study sample included 475 female sixth-graders. The students were recruited from 20 secondary schools in and nearby Munich. Students and their PE teachers voluntarily decided to participate in the project. Since the sample formed part of an intervention study promoting PA, the requested sample size was calculated under consideration of the intended increase in MVPA. Furthermore, using a formula by Rutterford et al. (2015), the estimated intracluster correlation, the supposed variation in class sizes and the levels of significance and power were considered as well. Sample size calculation resulted in a minimum of 467 students to be included in the analysis.

Students' mean age was 11.60 years ($SD = 0.55$, $N = 402$). They came from a variety of households with diverse socioeconomic backgrounds. Mean SES was 49.40 ($SD = 15.98$, $N = 389$). SES was assessed by means of four items asking the students to name and describe their parents' jobs. Answers were rated with regard to the International Socioeconomic Index of occupational status (ISEI) which is again based on the International Standard Classification of Occupation 2008 (ISCO-08) (Ganzeboom, 2010). If the jobs of both parents could be assigned an ISEI value, the job with the higher ISEI was considered (HISEI). A HISEI value could not be determined for every participant because some of the students gave vague answers or did not respond appropriately. The sample was on average normal weight (mean BMI = 19.52, $SD = 3.73$, $N = 361$). The number of indicated BMI values was reduced because some participants, both apparently normal weight and overweight girls, were not willing to be weighed.

The study was approved by the ethics commission of the Technical University of Munich (155/16 S) and the Bavarian State Ministry for Education and Culture.

Measures

The psychosocial variables were assessed by a paper-pencil questionnaire. The items were translated into German by means of a committee approach. Wording of the items was adapted to the language skills of the sample used in this study to enable students to fully understand the items and to answer properly without the constant help of the assessment team. Prior to the main assessments, the items were pilot tested by means of the pretest procedure (Brislin, 1970; Cha et al., 2007). Results of the pilot study supported reliability and factorial validity of the respective scales.

In this study, the baseline values of the CReActivity project (Demetriou and Bachner, 2019) were used. Data assessments started 5 weeks after the beginning of the school year. When answering the items, students were asked to think about the time period between the beginning of the school year and the assessment day.

BPN Support in PE

The 9-item Adolescent Psychological Need Support in Exercise Questionnaire (APNSEQ) was used to measure the support for BPN during PE (Emm-Collison et al., 2016). Participants responded on a 5-point Likert-type scale ranging from 1 ("Strongly disagree") to 5 ("Strongly agree"). The original items measure support from family, friends, and the PE teacher separately. In a sample comprising adolescents aged 11–15 years, a 3-factor solution of the PE teacher version was supported along with acceptable internal consistencies of the subscales autonomy, competence and relatedness support (Emm-Collison et al., 2016). In the present study, internal consistency of the three subscales was between 0.75 and 0.78.

BPN Satisfaction in PE and Leisure-Time

The twelve satisfaction items of the Basic Psychological Need Satisfaction and Frustration Scale (BPNSFS) by Chen et al. (2015) were adapted to measure PA-related satisfaction of BPN in the contexts of PE and leisure-time, respectively. The students had to answer on a 5-point Likert-type scale ranging from 1 ("Strongly disagree") to 5 ("Strongly agree"). Together with the respective frustration items, a 6-factor model fit the data well in a multinational sample (mean age = 20). Internal consistency of the BPN satisfaction subscales ranged from 0.65 to 0.88 (Chen et al., 2015). Since the items had originally been validated in a sample of mostly young adults, the items were largely simplified in this study. Internal consistency coefficients were between 0.78 and 0.85 (Sturm et al., 2020).

Motivation

To assess the quality and quantity of the sixth-graders' motivation and the respective regulatory styles, the Behavioral Regulation of Exercise Questionnaire 2 (BREQ-2) was used (Markland and Tobin, 2004). The questionnaire comprises 19 items from five subscales, each rated on a 5-point Likert-type scale. The subscale for integrated regulation was not included in the BREQ-2 since it could not be empirically distinguished from identified regulation. In an adult validation sample, a confirmatory factor analysis supported a 5-factor solution with Cronbach's Alpha being at least 0.73 for the respective scales (Markland and Tobin, 2004). In the present sixth-grade sample, internal consistency lay between 0.65 and 0.82. The subscales exhibited a simplex pattern, meaning that neighboring scales of the self-determination continuum had a higher positive correlation and scales further apart showed stronger negative correlations.

Self-Efficacy

The 8-item physical activity self-efficacy scale by Dishman et al. (2010) was used to assess the girls' self-efficacy regarding PA. The participants responded to a 5-point Likert-type scale ranging from 1 ("Strongly disagree") to 5 ("Strongly agree"). Originally validated in samples of sixth- and eighth-grade girls, confirmatory factor analyses found good fits for a unidimensional

model. Cronbach's Alpha in the different samples was 0.81 and 0.83, respectively (Dishman et al., 2010). In the present study, Cronbach's alpha was 0.84 (Bachner et al., 2020).

Social Support

The social support scale assessed friend and family support for PA (Dishman et al., 2010). The students had to indicate how often per week they were supported in being physically active by the respective social agents. They could choose from "never," "once," "sometimes," "almost every day," and "every day." Using the same samples as for validating the physical activity self-efficacy scale, a 2-factor solution was supported. Cronbach's Alpha of the two subscales ranged between 0.75 and 0.86 in the different samples (Dishman et al., 2010). In the sample used in this study, internal consistency was 0.74 for friend support and 0.73 for family support.

Physical Activity

Leisure-time MVPA was assessed by means of accelerometers (ActiGraph GT3X - wGT3X-BT). Participants had to wear the devices on the right hip for seven consecutive days except during water-based activities. Sampling rate was set to 30 Hz. On weekdays, participants had to put them on at the latest when they started their way to school. They had to wear the accelerometers until 9 pm unless they went to bed earlier. On weekend days, students had to put the devices on as soon as they got up until 9 pm or until they went to bed.

After collecting the accelerometers, the PA data were downloaded. An epoch length of 1 s was used to sum up the raw vector magnitude counts (10-second epochs were used for GT3X models because of their lower memory and battery capacities). It was refrained from using the low frequency extension filter. The algorithm by Choi et al. (2011) was used for wear-time validation. PA data was regarded as valid if a participant had worn the accelerometer for at least 8 h on at least three weekdays and one weekend day. For participants with a positive wear-time validation, the PA data was analyzed with the cut points by Hänggi et al. (2013) to finally estimate the average duration of MVPA per day for each participant. Cut point for MVPA was more than 3360 vector magnitude counts per minute. Hänggi et al. (2013) cut points were selected because they provide an assessment with a high resolution and because they were validated with the same data sampling and processing criteria as the ones chosen for this study (Migueles et al., 2017).

Procedure

Several weeks before the data assessments started, students and their parents received information letters regarding the purpose and the procedure of the upcoming assessments. Students only participated if they had provided a written consent form signed by them and their parents.

The data assessments were conducted at the beginning of PE classes. The students used codes to guarantee the anonymity of their data. Before the accelerometers were distributed, the students were explained how to put on the accelerometers by themselves. Additionally, the students received an information sheet summarizing the important details concerning the accelerometer use. After all students had put on the accelerometers correctly, they filled out the questionnaire. The actual PE class started as soon as every student had completed the questionnaire. On average, the students took about 20 min to complete the questionnaire.

Data Analysis

Self-Organizing Maps Analysis

The following input variables were included in the SOM analysis:

- BPN support in PE (three variables),
- BPN satisfaction in PE (three variables),
- BPN satisfaction in leisure-time (three variables),
- Amotivation, external regulation, introjected regulation, identified regulation, intrinsic regulation,
- Self-efficacy,
- Social support from friends and family (two variables).

The analysis was conducted with the MATLAB R2018a programme (Mathworks Inc., Natick, MA, United States) and the SOM toolbox (version 2.0 beta) for MATLAB (Vesanto et al., 1999). Questionnaire variables exhibited less than 4% of missing values. The non-significant Little's (1988) test indicated that they were missing completely at random ($\chi^2 = 8{,}529.19$, df $= 8634$, $p = 0.787$). Missing values were replaced by applying the 5NN imputation method based on the Euclidean distance to the five nearest neighbors of the respective case (Hastie et al., 2001; Troyanskaya et al., 2001).

The SOM analysis classifies the participants and creates typical profiles based on the participants' similarities regarding their values on the input variables. The SOM procedure comprises three steps (Pellicer-Chenoll et al., 2015): (1) the construction of the neuron network, consisting of 16×7 neurons in this study (height $\times$ width), (2) the initialization of the SOM, when each neuron is assigned a value or weight for each input variable by two different ways (i.e., randomized and linear initialization), and (3) the training, when the initial values or weights of the neurons are further modified, which is led by two different training algorithms (i.e., sequential and batch) (Oliver Gasch et al., 2016).

The training is an iterative process and the neuronal weights are modified in each iteration in order to find the best solution. This process depends on several factors. Every participant is represented by an input vector. As soon as an input vector is introduced to the neuron network, the neurons try to attract the input vector. A neuron succeeds when it adapts its weight vector until it exhibits the smallest Euclidean distance between its own weight vector and the input vector it tries to gather. Accordingly, every neuron finally has a weight vector most similar to the input vectors it has gathered (Estevan et al., 2019). To what extent a neuron is able to adapt, is again determined by two aspects: (a) the learning ratio, which starts with a high value and decreases during the training process, and (b) the neighborhood function affecting the adaptation magnitude of the winning neuron and the other neurons. More precisely, the winning neuron and its closest neighbors adapt better to a given input vector than the neurons further away in the neuron network. The adaptation is repeated until the training process ends (Pellicer-Chenoll et al., 2015).

Taking into consideration that the final analysis is based on a random procedure (e.g., initialization and entry order of the input vector), the process described above was conducted repeatedly with the number of iterations fixed to 100. In the end, 1600 SOMs were created as two initialization methods, two training algorithms and four different neighborhood functions were computed (i.e., $100 \times 2 \times 2 \times 4$). After the quantization and topographical errors had been multiplied, the map with the minimum error was finally chosen (Estevan et al., 2019; Molina-García et al., 2019).

In order to convert the results illustrated by the respective component planes into a more ostensive solution, the neurons were classified into superordinate clusters according to the values on the input variables with help of a k-means method. The number of clusters was restricted to range between 2 and 10 in order to avoid a high number of profiles making the solution difficult to interpret. The final number of clusters depends on the quantization error and the number of participants per cluster. The quantization error describes the average Euclidean difference between the input vectors and the cluster vectors they are allocated to Kohonen et al. (2009). While the quantization error should be low, the clusters should contain a relevant number of participants to truly represent common profiles. By means of these clusters, typical profiles of the sixth-graders with regard to the input variables were described.

Finally, differences between the clusters regarding the respective SOM input variables, BMI, SES, and MVPA were tested by means of univariate ANOVAs (significance level = 0.05) with Bonferroni corrected *post hoc* tests.

RESULTS

Figure 1 shows the results of the SOM analysis and how they were derived.

According to the values on the input variables, each participant is placed in a neuron (illustrated as hexagons). Thus, participants who are located in the same neuron exhibit similar values on the input variables. For each input variable a component plane was created (**Figure 1A**). A given participant is located in the same neuron in each component plane. This illustrates which characteristics regarding the input variables are typically shared by particular groups of the sample.

Making the shared characteristics more visible, SOM and *k*-means analyses indicated that with three clusters, an optimal combination of a low quantization error (**Figure 1B**) and a considerable number of participants per cluster ($\geq$135; **Figure 1C**) was found. Therefore, the neurons were classified into three superordinate clusters (**Figure 1D**).

The descriptive statistics regarding the SOM input variables and MVPA as well as the pairwise comparisons between the three clusters are given in **Table 1**.

ANOVAs showed a significant effect of cluster membership on every SOM input variable. Cluster affiliation explained on average 28.4% of the variance in the respective input variables. Cluster 3 represents the positive cluster, as on every BPN support and satisfaction variable as well as on identified and intrinsic regulation, self-efficacy and the two social support variables, students of Cluster 3 exhibited significantly higher values than clusters 1 and 2. Cluster 1, the so-called negative cluster, mainly contained the participants from opposite sides of the sample distribution showing significantly lower values than clusters 2 and 3 in these input variables. Consequently, Cluster 2 constitutes the medium cluster. The negative cluster had on average higher values on amotivation than the medium and positive clusters. The positive cluster comprised both the participants with the lowest and the participants with the highest external regulation. On average, their external regulation was significantly higher than in the medium cluster and lower than in the negative cluster. The participants with the highest values on introjected regulation were allocated to the positive cluster, whose mean value was significantly higher than the one of the medium cluster.

The clusters' mean MVPA differed significantly ($F_{2,472} = 7.46$, $p = 0.001$, $\eta^2 = 0.03$). With 91.40 min MVPA per day, the positive cluster had significantly higher mean values than the negative cluster (81.58 min) and the medium cluster (85.11 min).

ANOVAs showed no effect of cluster affiliation on SES, but a significant effect on BMI ($F_{2,358} = 9.66$, $p < 0.001$, $\eta^2 = 0.05$) with the participants in the positive cluster having the lowest and the ones in the negative cluster the highest mean BMI.

DISCUSSION

Based on the assumption that PA-related psychosocial variables do not develop independently from one another within a given person, it was examined which profiles regarding these variables can be observed in female sixth-graders and whether these profiles are in line with the underlying theories (Bergman and Lundh, 2015; Demetriou and Bachner, 2019). By means of a SOM analysis, self-consistent profiles contributing to the explanation of MVPA were differentiated and it is shown that strengthening these resources in female sixth-graders can lead the way to healthy PA behavior.

Referring to research questions 1 and 2, the characteristics of the superordinate clusters are described and their accordance with theoretical assumptions is discussed. With regard to participants in cluster 3, called the positive cluster, it becomes clear that the students who felt most supported in their BPN during PE were also the ones who felt most satisfied in their BPN during PE and LT. This finding is in line with existing literature (Standage et al., 2012; Wang, 2017; Kalajas-Tilga et al., 2019). In line with SDT assumptions (Ryan and Deci, 2000), the PA behavior of these girls was mainly self-determined as they had the highest values on identified and intrinsic regulation (McDavid et al., 2014; Wang, 2017; Kalajas-Tilga et al., 2019). Additionally, the students in the positive cluster exhibited the highest values on self-efficacy and benefited from the highest social support by friends and families, which corresponds to the assumptions of the social-cognitive theory (Bandura, 1997).

A coherent picture evolves when participants of cluster 1, the negative cluster, are added. Since the study sample generally exhibited a healthy MVPA level and had medium to large resources regarding the psychosocial variables, the values of the

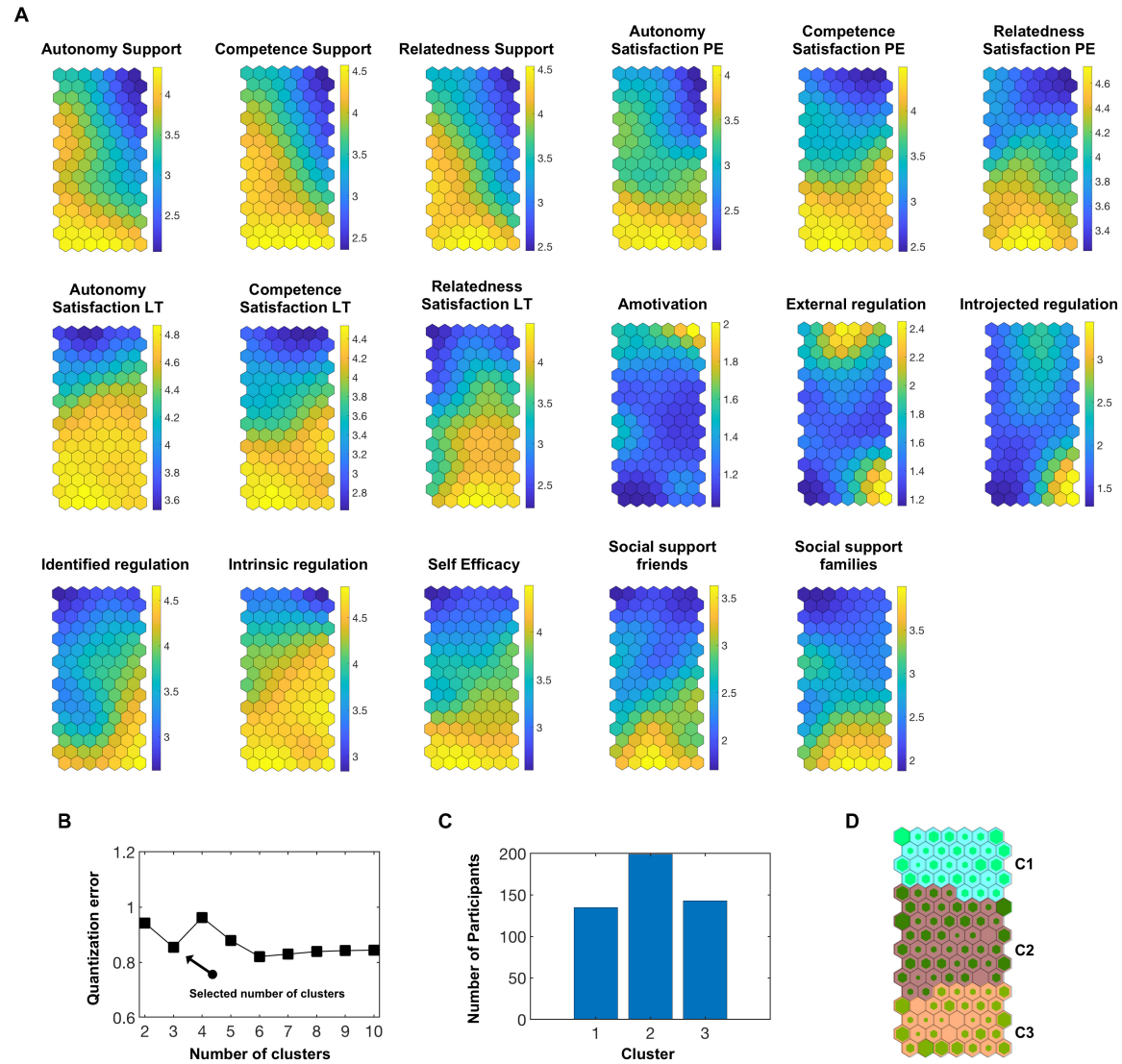

FIGURE 1 | Component planes, clusters and hits obtained by the SOM analysis. **(A)** Component planes of the input variables. Yellow neurons indicate relatively high values, dark blue neurons indicate relatively low values, oriented toward the sample distribution. **(B)** Quantization error according to the possible number of clusters selected. **(C)** Number of participants per cluster for the chosen cluster solution. **(D)** Hits map with the three superordinate clusters C1 – C3. The more a neuron is filled with green, the higher the number of participants assigned to the neuron. PE = physical education; LT = leisure-time.

negative cluster are not worrying when seen from an absolute perspective. However, in relation to the medium and the positive cluster, clear differences emerged. Compared to the rest of the sample, students in the negative cluster reported a relatively low BPN support and BPN satisfaction in PE and LT (Standage et al., 2012; Wang, 2017; Kalajas-Tilga et al., 2019). The girls in the negative cluster showed on average the highest amotivation and their PA behavior was provoked by external regulation to a substantial extent. This finding is again in agreement with the assumptions of SDT (Ryan and Deci, 2000; McDavid et al., 2014; Wang, 2017; Kalajas-Tilga et al., 2019). Furthermore, self-efficacy of this cluster was relatively low and the students received less social support than the rest of the sample, which is again in line with the SCT (Bandura, 1997).

With the exception of external and introjected regulation, the mean values of cluster 2, the medium cluster, were located between the ones of the positive and the negative cluster on every variable. Thereby, the medium cluster completes the generally self-consistent picture, which was revealed by the unsupervised SOM algorithm. Within the participants, the constructs assessed in the CReActivity project (Demetriou and Bachner, 2019) relate to each other in a coherent way, which ultimately leads to a self-consistent superordinate three-cluster solution describing typical profiles of PA-related psychosocial constructs. This indicates that the different psychosocial resources do not develop independently from one another within a given person, which finally supports the use of a person-oriented approach (e.g., Teixeira et al., 2012; Bergman and Lundh, 2015).

The three clusters differed significantly in their average BMI values, with the positive cluster comprising the students with the lowest mean BMI and the negative cluster comprising the ones with the highest mean BMI. More importantly, with reference to research question 3, the students of the positive cluster exhibited a significantly higher MVPA level than the other clusters. A student of the positive cluster exhibits on average around 45 min more MVPA per week than a student of the medium cluster. The mean difference between the positive and negative clusters amounts to almost 70 min per week, which equals one additional day of healthy MVPA behavior each week (World Health Organization [WHO], 2018). Since MVPA was in general on a relatively high level in this sample, the magnitude of the differences between the clusters should be regarded as even more meaningful. Thus, as hypothesized, a self-consistent superordinate cluster solution contributed to the explanation of the students' MVPA. Thereby, the power of the assessed variables as determinants of PA behavior in children and adolescents is supported and the significance of the SDT for the explanation of PA is underlined (Bauman et al., 2012; Owen et al., 2014; Laird et al., 2016; Wang, 2017; Kalajas-Tilga et al., 2019). This is also in line with recent studies relating profiles of PA-related behavioral regulations with actual PA behavior in adult samples (Lindwall et al., 2017; Emm-Collison et al., 2020). Since MVPA is considered the most important criterion variable here, this result, together with the respective BMI values, further suggests a good criterion validity of the superordinate three-cluster solution (Sarstedt and Mooi, 2019). Equally important, this finding argues for the input variables as promising mediators in a subsequent intervention to promote the MVPA of female sixth-graders (Demetriou and Bachner, 2019).

Thus far, the self-consistent superordinate cluster solution might suggest a strong general factor regarding PA-related psychosocial resources as in most cases the ranking of a given participant was on a highly comparable level across the different psychosocial determinants. However, a main strength of the person-oriented approach (Bergman and Lundh, 2015) in general and the SOM analysis (Kohonen, 1995) in particular becomes clear when looking at the clusters' values on external regulation. Both the negative and positive cluster included participants with relatively high values on external regulation. By means of the SOM analysis, a non-linear relationship and a dual role of external regulation appeared when looking at the respective MVPA levels. On the one hand, relatively high values in external regulation can constitute the complementary counterpart of a deficit in intrinsic regulation, as can be seen in the negative cluster, which exhibited the lowest MVPA level (Ryan and Deci, 2000). A subgroup of students ($n = 40$) within the superordinate positive cluster, on the other hand, do not meet this conception, as they were both intrinsically motivated (intrinsic regulation $\geq$4.5) and reported a considerable level of external regulation ($\geq$2.25). In fact, these girls engaged in 95.53 min of MVPA per day, which is higher than the average value of the positive cluster. More than that, they had even higher MVPA values than the students with extremely high values in intrinsic regulation (>4.7) and extremely low values in

TABLE 1 | Means, standard deviations, and pairwise comparisons regarding SOM input variables and MVPA.

	Autonomy Support	Competence Support	Relatedness Support	Autonomy Satisfaction PE	Competence Satisfaction PE	Relatedness Satisfaction PE	Autonomy Satisfaction LT	Competence Satisfaction LT	Relatedness Satisfaction LT
Cluster 1	2.83	3.10	3.07	2.62	2.84	3.53	3.81	2.96	2.68
($n = 135$)	(0.84)	(0.78)	(0.76)	(0.69)	(0.69)	(0.79)	(0.79)	(0.70)	(0.83)
Cluster 2	3.36	3.72	3.67	3.16	3.64	3.98	4.57	3.83	3.46
($n = 199$)	(0.80)	(0.83)	(0.82)	(0.76)	(0.63)	(0.78)	(0.49)	(0.64)	(0.93)
Cluster 3	4.01	4.32	4.16	3.87	4.33	4.51	4.77	4.39	4.00
($n = 141$)	(0.69)	(0.60)	(0.60)	(0.63)	(0.54)	(0.51)	(0.38)	(0.58)	(0.84)
Total	3.40	3.72	3.65	3.22	3.62	4.01	4.41	3.75	3.40
($N = 475$)	(0.90)	(0.88)	(0.87)	(0.85)	(0.84)	(0.80)	(0.68)	(0.84)	(1.01)
	Amotivation	**External Regulation**	**Introjected Regulation**	**Identified Regulation**	**Intrinsic Regulation**	**Self-efficacy**	**Social Support Friends**	**Social Support Family**	**MVPA in min/day**
Cluster 1	1.59	1.98	2.08	3.04	3.44	2.83	1.92	2.11	81.58
($n = 140$)	(0.64)	(0.87)	$(0.90)^{3,n.s.}$	(0.75)	(0.84)	(0.64)	(0.73)	(0.70)	$(20.32)^{2,n.s.}$
Cluster 2	1.19	1.38	1.78	3.66	4.43	3.62	2.51	2.72	85.11
($n = 174$)	$(0.38)^{3,n.s.}$	(0.49)	(0.68)	(0.72)	(0.55)	(0.63)	(0.80)	(0.75)	$(21.17)^{1,n.s.}$
Cluster 3	1.16	1.67	2.24	4.23	4.74	4.29	3.18	3.56	91.40
($n = 163$)	$(0.42)^{2,n.s.}$	(0.85)	$(1.14)^{1,n.s.}$	(0.68)	(0.45)	(0.49)	(0.84)	(0.81)	(22.99)
Total	1.30	1.64	2.00	3.65	4.24	3.60	2.54	2.80	85.97
($N = 475$)	(0.51)	(0.77)	(0.92)	(0.85)	(0.81)	(0.82)	(0.93)	(0.94)	(21.79)

PE, physical education; LT, leisure-time; MVPA, moderate to vigorous physical activity; n.s., not significant.

Data are expressed as means (standard deviations of the means); each pairwise comparison between the clusters was significant ($p < 0.01$) except those marked with superscript numbers indicating non-significant differences to the specified cluster (Bonferroni corrected).

external regulation (<1.2), who averaged 89.35 min of MVPA per day ($n = 97$). This is similar to the results of a study using self-report measures in a sample of young adolescents, which reported that students with the highest PA levels were the ones who showed high levels of intrinsic regulation and moderate-to-high levels of extrinsic regulation. This supports the assumption that in these cases, external regulation does not harm intrinsic regulation but might even complementarily add to it, which can be beneficial with regard to PA behavior (Harackiewicz, 1979; Ingledew and Markland, 2008). Thus, in these cases, the nature of the external motivation seems to be compatible with the autonomous motivation (Ryan and Deci, 2000; Kilpatrick et al., 2005). Only if the nature of external events comply with personal values and preferences, an originally external motivation can be introjected and finally transformed into more autonomous forms of regulation (Teixeira et al., 2012). This requirement can be met when external events or rewards are conducive to the BPN (Vansteenkiste et al., 2010). An example would be positive feedback, which is deemed to support competence. The fact that students in the subgroup with high levels in intrinsic regulation and moderate levels in external regulation are the only ones with moderate-to-high values in introjected regulation, indicates that these requirements were sufficiently met in these students. Additionally, this shows that MVPA of some adolescents can be regulated by external, introjected and autonomous forces at the same time, which is in line with the findings of other studies that examined groups of adults and older adolescents, respectively (Lindwall et al., 2017; Bechter et al., 2018). Furthermore, this result suggests that prevention or intervention programs should not only focus on supporting autonomous motivation, because the promotion of external motivation does not necessarily undermine the existing autonomous motivation, but can support or add to it (e.g., Ingledew and Markland, 2008). Moreover, this indicates the need and the potential of tailored interventions designed to promote PA of distinct subgroups with specific baseline characteristics and conditions (Hagger, 2010; Bock et al., 2014; Gut et al., 2020). For example, MVPA of the subgroup with the highest values in intrinsic regulation and the lowest values in external regulation might be enhanced in an intervention using the potential of external incentives that are compatible with their existing self-determined motivation (Ryan and Deci, 2000; Kilpatrick et al., 2005; Vansteenkiste et al., 2010).

Using a variable-based approach with analyses conducted on an aggregated group level (Bergman and Lundh, 2015), the findings on subgroups with different characteristics regarding external regulation would not have appeared. Instead, the magnitude of the correlation between external regulation and MVPA would have decreased. In the person-oriented SOM analysis, however, one benefits from obtaining results both in numerical form and results that are presented graphically (**Figure 1A**). This way, after the reduction of the data into an ostensive superordinate cluster solution, the visual presentation of the results makes it possible to quickly identify potential subgroups within the clusters that might require specific attention. The advantage of the visual presentation of SOM results is not given in other clustering techniques like k-means. Together with the advantages outlined above, these points underline the suitability of SOM for accurately reducing data complexity without the risk of overlooking subgroups with special demands that go beyond the superordinate cluster solution. Thus, the SOM analysis proves valuable in explaining PA behavior, as it is able to go beyond the examination of associations between variables. Rather, it enables the differentiation between distinct groups of people whose respective demands and deficits can then be answered more specifically by developing tailored interventions (Lindwall et al., 2017; Emm-Collison et al., 2020; Gut et al., 2020).

However, some limitations of this study need to be addressed. On the one hand, the main goal of a cluster analysis is to reduce the complexity of the given information transforming it into an applicable solution (Hofstetter et al., 2014). On the other hand, reducing the information usually leads to a decreased precision (Steinley, 2006). The ultimate task is to allocate the participants precisely, without increasing the number of clusters to an extent that ultimately counteracts the original purpose of a cluster analysis. The low quantization error of the superordinate three-cluster solution found here indicates a good trade-off, which is further underlined by the fact that the error would not have been substantially lower with a higher number of clusters. However, since the superordinate three-cluster solution is based on a combination of all 17 input variables, it does not differentiate equally well for each input variable between participants with relatively high, medium and low values. This can be seen in the medium cluster, which showed a less homogeneous profile. Some students, for example, reported a high competence support in PE, but actually perceived themselves as less competent than other students reporting the same level of competence support. Although this might motivate further research into what might interfere with the path from competence support to competence satisfaction among these students, this can be seen as a minor deficit in selectivity for the benefit of a parsimonious and applicable cluster solution.

In addition, according to the Health Action Process Approach (HAPA; Schwarzer, 2008), the process of adopting a healthy behavior comprises both motivational components resulting in an intention, and volitional processes that finally lead to the actual behavior. The psychosocial determinants used to explain PA behavior in this study solely focused on constructs of the motivational spectrum. Volitional constructs could help to bridge this intention-behavior gap to some extent as they are more proximal to the actual behavior. By means of a person-oriented approach in a sample of ninth-grade students (Gut et al., 2020), levels in motivational and volitional psychosocial constructs were examined. For most adolescents, motivation and volition were highly similar. However, there was a small group with high self-determined motivation and strong intention but low values in action planning whose exercise and sport activity level was clearly lower compared to the participants with a high motivation and high volition profile. This suggests that the explanation of PA behavior could have been greater by including volitional constructs as well.

Furthermore, the findings should be verified in a more diverse sample with regard to gender and age. In addition, it

would be interesting to replicate the analysis in a sample with lower MVPA levels.

CONCLUSION

Based on the theoretical framework of the YPAPM, the SOM analysis revealed three superordinate clusters of female sixth-graders with relatively high, medium and low psychosocial resources regarding PA. The three-cluster solution represents a self-consistent picture in accordance with the theoretical assumptions and contributes to the explanation of MVPA. The results support the use of a person-oriented approach, as the SOM analysis could show that the different psychosocial resources do not develop independently of one another within a given person (e.g., Teixeira et al., 2012; Bergman and Lundh, 2015). In addition to the superordinate cluster solution, the analysis enabled the detection of a specific subgroup, which provided insights into the coexistence and interaction of behavioral regulations in PA. The psychosocial variables assessed in the CReActivity project are deemed promising mediators in promoting MVPA in this sample. Finally, the SOM analysis proved to be a valuable tool for differentiating between distinct profiles regarding PA-related psychosocial resources and for identifying specific subgroups with special characteristics, which would have remained undiscovered using variable-based approaches.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics commission of the Technical University of Munich. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

YD, JB and DS designed the study. YD and JB engaged in the funding acquisition. JB and DS conducted the data collection. XG-M and JB analyzed the data. XG-M, JM-G, and JB interpreted the results. JB wrote the original draft of the manuscript. YD and JM-G supervised the cooperation. All authors contributed to the revision of the manuscript and have read and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.580563/full#supplementary-material

REFERENCES

Astel, A., Tsakovski, S., Barbieri, P., and Simeonov, V. (2007). Comparison of self-organizing maps classification approach with cluster and principal components analysis for large environmental data sets. *Water Res.* 41, 4566–4578. doi: 10.1016/j.watres.2007.06.030

Bachner, J., Sturm, D. J., Haug, S., and Demetriou, Y. (2020). Multi-level validation of the German physical activity self-efficacy scale in a sample of female sixth-graders. *BMC Public Health* 20:979. doi: 10.1186/s12889-020-09096-4

Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. New York, NY: W H Freeman & Co.

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J., and Martin, B. W. (2012). Correlates of physical activity: why are some people physically active and others not? *Lancet* 380, 258–271. doi: 10.1016/s0140-6736(12)60735-1

Bechter, B. E., Dimmock, J. A., Howard, J. L., Whipp, P. R., and Jackson, B. (2018). Student motivation in high school physical education: a latent profile analysis approach. *J. Sport Exerc. Psychol.* 40, 206–216. doi: 10.1123/jsep.2018-0028

Bergman, L. R., and Andersson, H. (2010). The person and the variable in developmental psychology. *Z. Psychol.* 218, 155–165. doi: 10.1027/0044-3409/a000025

Bergman, L. R., and Lundh, L.-G. (2015). Introduction: the person-oriented approach: roots and roads to the future. *J. Pers. Oriented Res.* 1, 1–6. doi: 10.17505/jpor.2015.01

Bock, C., Jarczok, M. N., and Litaker, D. (2014). Community-based efforts to promote physical activity: a systematic review of interventions considering mode of delivery, study quality and population subgroups. *J. Sci. Med. Sport* 17, 276–282. doi: 10.1016/j.jsams.2013.04.009

Brislin, R. W. (1970). Back-translation for cross-cultural research. *J. Cross Cult. Psychol.* 1, 185–216. doi: 10.1177/135910457000100301

Buchan, D. S., Ollis, S., Thomas, N. E., and Baker, J. S. (2012). Physical activity behaviour: an overview of current and emergent theoretical practices. *J. Obes.* 2012:546459. doi: 10.1155/2012/546459

Budayan, C., Dikmen, I., and Birgonul, M. T. (2009). Comparing the performance of traditional cluster analysis, self-organizing maps and fuzzy C-means method for strategic grouping. *Expert Syst. Appl.* 36, 11772–11781. doi: 10.1016/j.eswa.2009.04.022

Bush, P. L., and MacDonald, C. (2015). Promoting physical activity among adolescents: recommendations from correlation research. *Retos* 28, 184–198. doi: 10.47197/retos.v0i28.34953

Cha, E. S., Kim, K. H., and Erlen, J. A. (2007). Translation of scales in cross-cultural research: issues and techniques. *J. Adv. Nurs.* 58, 386–395. doi: 10.1111/j.1365-2648.2007.04242.x

Chatzisarantis, N. L., and Hagger, M. S. (2009). Effects of an intervention based on self-determination theory on self-reported leisure-time physical activity participation. *Psychol. Health* 24, 29–48. doi: 10.1080/08870440701809533

Chen, B., Vansteenkiste, M., Beyers, W., Boone, L., Deci, E. L., Van der Kaap-Deeder, J., et al. (2015). Basic psychological need satisfaction, need frustration, and need strength across four cultures. *Motiv. Emot.* 39, 216–236. doi: 10.1007/s11031-014-9450-1

Choi, L., Liu, Z., Matthews, C. E., and Buchowski, M. S. (2011). Validation of accelerometer wear and nonwear time classification algorithm. *Med. Sci. Sports Exerc.* 43, 357–364. doi: 10.1249/MSS.0b013e3181ed61a3

Cooper, A., Goodman, A., Page, A., Sherar, L., Esliger, D., Sluijs, E., et al. (2015). Objectively measured physical activity and sedentary time in youth: the international children's accelerometry database (ICAD). *Int. J. Behav. Nutr. Phys. Act.* 12:113. doi: 10.1186/s12966-015-0274-5

Corder, K., van Sluijs, E. M., Steele, R. M., Stephen, A. M., Dunn, V., Bamber, D., et al. (2011). Breakfast consumption and physical activity in British adolescents. *Br. J. Nutr.* 105, 316–321. doi: 10.1017/s0007114510003272

Cortis, C., Puggina, A., Pesce, C., Aleksovska, K., Buck, C., Burns, C., et al. (2017). Psychological determinants of physical activity across the life course: a "determinants of diet and physical activity" (DEDIPAC) umbrella systematic literature review. *PLoS One* 12:e0182709. doi: 10.1371/journal.pone.0182709

Deci, E. L., and Ryan, R. M. (2000). The "what" and "why" of goal pursuits: human needs and the self-determination of behavior. *Psychol. Inq.* 11, 227–268. doi: 10.1207/S15327965PLI1104_01

Demetriou, Y., and Bachner, J. (2019). A school-based intervention based on self-determination theory to promote girls' physical activity: study protocol of the CReActivity cluster randomised controlled trial. *BMC Public Health* 19:519. doi: 10.1186/s12889-019-6817-y

Dishman, R. K., Hales, D. P., Sallis, J. F., Saunders, R., Dunn, A. L., Bedimo-Rung, A. L., et al. (2010). Validity of social-cognitive measures for physical activity in middle-school girls. *J. Pediatr. Psychol.* 35, 72–88. doi: 10.1093/jpepsy/jsp031

Dumith, S. C., Gigante, D. P., Domingues, M. R., and Kohl, H. W. III (2011). Physical activity change during adolescence: a systematic review and a pooled analysis. *Int. J. Epidemiol.* 40, 685–698. doi: 10.1093/ije/dyq272

Emm-Collison, L. G., Sebire, S. J., Salway, R., Thompson, J. L., and Jago, R. (2020). Multidimensional motivation for exercise: a latent profile and transition analysis. *Psychol. Sport Exerc.* 47, 101619. doi: 10.1016/j.psychsport.2019.101619

Emm-Collison, L. G., Standage, M., and Gillison, F. B. (2016). Development and validation of the adolescent psychological need support in exercise questionnaire. *J. Sport Exerc. Psychol.* 38, 505–520. doi: 10.1123/jsep.2015-0220

Estevan, I., García-Massó, X., Molina-García, J., and Barnett, L. M. (2019). Identifying profiles of children at risk of being less physically active: an exploratory study using a self-organised map approach for motor competence. *J. Sports Sci.* 37, 1356–1364. doi: 10.1080/02640414.2018.1559491

Finger, J. D., Varnaccia, G., Borrmann, A., Lange, C., and Mensink, G. (2018). Körperliche aktivität von kindern und jugendlichen in deutschland – querschnittergebnisse aus KiGGS welle 2 und trends. *J. Health Monitor.* 3, 24–31. doi: 10.25646/2957.2

Ganzeboom, H. (2010). "A new international socio-economic index (ISEI) of occupational status for the international standard classification of occupation 2008 (ISCO-08) constructed with data from the ISSP 2002–2007," in *Paper Presented at the Annual Conference of International Social Survey Programme*, Lisbon.

Granger, E., Di Nardo, F., Harrison, A., Patterson, L., Holmes, R., and Verma, A. (2017). A systematic review of the relationship of physical activity and health status in adolescents. *Eur. J. Public Health* 27(Suppl._2), 100–106. doi: 10.1093/eurpub/ckw187

Gut, V., Schmid, J., and Conzelmann, A. (2020). The interaction of behavioral context and motivational-volitional factors for exercise and sport in adolescence: patterns matter. *BMC Public Health* 20:570. doi: 10.1186/s12889-020-08617-5

Guthold, R., Stevens, G. A., Riley, L. M., and Bull, F. C. (2020). Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1.6 million participants. *Lancet Child Adolesc. Health* 4, 23–35. doi: 10.1016/S2352-4642(19)30323-2

Hagger, M. (2010). Current issues and new directions in psychology and health: physical activity research showcasing theory into practice. *Psychol. Health* 25, 1–5. doi: 10.1080/08870440903268637

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., and Ekelund, U. (2012). Global physical activity levels: surveillance progress, pitfalls, and prospects. *Lancet* 380, 247–257. doi: 10.1016/S0140-6736(12)60646-1

Hallal, P. C., Wells, J. C., Reichert, F. F., Anselmi, L., and Victora, C. G. (2006). Early determinants of physical activity in adolescence: prospective birth cohort study. *BMJ* 332, 1002–1007. doi: 10.1136/bmj.38776.434560.7C

Hänggi, J. M., Phillips, L. R., and Rowlands, A. V. (2013). Validation of the GT3X ActiGraph in children and comparison with the GT1M ActiGraph. *J. Sci. Med. Sport* 16, 40–44. doi: 10.1016/j.jsams.2012.05.012

Harackiewicz, J. M. (1979). The effects of reward contingency and performance feedback on intrinsic motivation. *J. Pers. Soc. Psychol.* 37, 1352–1363. doi: 10.1037/0022-3514.37.8.1352

Hastie, T., Tibshirani, R., Sherlock, G., Eisen, M., Brown, P., and Botstein, D. (2001). *Imputing Missing Data for Gene Expression Arrays*. Technical Report No. 1. Stanford, CA: Stanford University Department of Statistics.

Herrero-Herrero, M., García-Massó, X., Martínez-Corralo, C., Prades-Piñón, J., and Sanchis-Alfonso, V. (2017). Relationship between the practice of physical activity and quality of movement in adolescents: a screening tool using self-organizing maps. *Phys. Sportsmed.* 45, 271–279. doi: 10.1080/00913847.2017.1327303

Hofstetter, H., Dusseldorp, E., van Empelen, P., and Paulussen, T. W. (2014). A primer on the use of cluster analysis or factor analysis to assess co-occurrence of risk behaviors. *Prev. Med.* 67, 141–146. doi: 10.1016/j.ypmed.2014.07.007

Ingledew, D. K., and Markland, D. (2008). The role of motives in exercise participation. *Psychol. Health* 23, 807–828. doi: 10.1080/08870440701405704

Jaakkola, T., Washington, T., and Yli-Piipari, S. (2012). The association between motivation in school physical education and self-reported physical activity during Finnish junior high school. *Eur. Phys. Educ. Rev.* 19, 127–141. doi: 10.1177/1356336x12465514

Kalajas-Tilga, H., Koka, A., Hein, V., Tilga, H., and Raudsepp, L. (2019). Motivational processes in physical education and objectively measured physical activity among adolescents. *J. Sport Health Sci.* 9, 462–471. doi: 10.1016/j.jshs.2019.06.001

Kilpatrick, M., Hebert, E., and Bartholomew, J. (2005). College students' motivation for physical activity: differentiating men's and women's motives for sport participation and exercise. *J. Am. Coll. Health* 54, 87–94. doi: 10.3200/JACH.54.2.87-94

Kohonen, T. (1995). *The Self-Organizing Map*. Heidelberg: Springer-Verlag.

Kohonen, T., Nieminen, I. T., and Honkela, T. (2009). "On the quantization error in SOM vs. VQ: a critical and systematic study," in *Advances in Self-Organizing Maps. WSOM 2009. Lecture Notes in Computer Science*, Vol. 5629, eds J. C. Príncipe and R. Miikkulainen (Berlin: Springer).

Laird, Y., Fawkner, S., Kelly, P., McNamee, L., and Niven, A. (2016). The role of social support on physical activity behaviour in adolescent girls: a systematic review and meta-analysis. *Int. J. Behav. Nutr. Phys. Act.* 13:79. doi: 10.1186/s12966-016-0405-7

Laird, Y., Fawkner, S., and Niven, A. (2018). A grounded theory of how social support influences physical activity in adolescent girls. *Int. J. Qual. Stud. Health Well Being* 13:1435099. doi: 10.1080/17482631.2018.1435099

Lindwall, M., Ivarsson, A., Weman-Josefsson, K., Jonsson, L., Ntoumanis, N., Patrick, H., et al. (2017). Stirring the motivational soup: within-person latent profiles of motivation in exercise. *Int. J. Behav. Nutr. Phys. Act.* 14:4. doi: 10.1186/s12966-017-0464-4

Little, R. J. A. (1988). A test of missing completely at random for multivariate data with missing values. *J. Am. Stat. Assoc.* 83, 1198–1202. doi: 10.1080/01621459.1988.10478722

Lubans, D. R., Foster, C., and Biddle, S. J. (2008). A review of mediators of behavior in interventions to promote physical activity among children and adolescents. *Prev. Med.* 47, 463–470. doi: 10.1016/j.ypmed.2008.07.011

Markland, D., and Tobin, V. (2004). A modification to the behavioural regulation in exercise questionnaire to include an assessment of amotivation. *J. Sport Exerc. Psychol.* 26, 191–196. doi: 10.1123/jsep.26.2.191

McDavid, L., Cox, A. E., and McDonough, M. H. (2014). Need fulfillment and motivation in physical education predict trajectories of change in leisure-time physical activity in early adolescence. *Psychol. Sport Exerc.* 15, 471–480. doi: 10.1016/j.psychsport.2014.04.006

McKinney, J., Lithwick, D. J., Morrison, B., Nazzari, H., Isserow, S. H., Heilbron, B., et al. (2016). The health benefits of physical activity and cardiorespiratory fitness. *B. C. Med. J.* 58, 131–137.

Melo Riveros, N. A., Cardenas Espitia, B. A., and Aparicio Pico, L. E. (2019). Comparison between K-means and self-organizing maps algorithms used for diagnosis spinal column patients. *Inform. Med. Unlocked* 16:100206. doi: 10.1016/j.imu.2019.100206

Mendonça, G., Cheng, L. A., Mélo, E. N., and de Farias Júnior, J. C. (2014). Physical activity and social support in adolescents: a systematic review. *Health Educ. Res.* 29, 822–839. doi: 10.1093/her/cyu017

Migueles, J. H., Cadenas-Sanchez, C., Ekelund, U., Delisle Nystrom, C., Mora-Gonzalez, J., Lof, M., et al. (2017). Accelerometer data collection and processing criteria to assess physical activity and other outcomes: a systematic review and practical considerations. *Sports Med.* 47, 1821–1845. doi: 10.1007/s40279-017-0716-0

Molina-García, J., García-Massó, X., Estevan, I., and Queralt, A. (2019). Built environment, psychosocial factors and active commuting to school in adolescents: clustering a self-organizing map analysis. *Int. J. Environ. Res. Public Health* 16:83. doi: 10.3390/ijerph16010083

Molina-García, J., Queralt, A., Adams, M. A., Conway, T. L., and Sallis, J. F. (2017). Neighborhood built environment and socio-economic status in relation to multiple health outcomes in adolescents. *Prev. Med.* 105, 88–94. doi: 10.1016/j.ypmed.2017.08.026

Oliver Gasch, E., Vallés Pérez, I., Baños Rivera, R. M., Cebolla, I., Martí, A. J., Botella Arbona, C., et al. (2016). Visual data mining with self-organizing maps for "self-monitoring" data analysis. *Sociol. Methods Res.* 2016, 1–15.

Owen, K. B., Smith, J., Lubans, D. R., Ng, J. Y. Y., and Lonsdale, C. (2014). Self-determined motivation and physical activity in children and adolescents: a systematic review and meta-analysis. *Prev. Med.* 67, 270–279. doi: 10.1016/j.ypmed.2014.07.033

Pellicer-Chenoll, M., García-Massó, X., Morales, J., Serra-Ano, P., Solana-Tramunt, M., Gonzalez, L. M., et al. (2015). Physical activity, physical fitness and academic achievement in adolescents: a self-organizing maps approach. *Health Educ. Res.* 30, 436–448. doi: 10.1093/her/cyv016

Rodgers, W. M., Markland, D., Selzler, A.-M., Murray, T. C., and Wilson, P. M. (2014). Distinguishing perceived competence and self-efficacy: an example from exercise. *Res. Q. Exerc. Sport* 85, 527–539. doi: 10.1080/02701367.2014.961050

Rutterford, C., Copas, A., and Eldridge, S. (2015). Methods for sample size determination in cluster randomized trials. *Int. J. Epidemiol.* 44, 1051–1067. doi: 10.1093/ije/dyv113

Ryan, R. M., and Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *Am. Psychol.* 55, 68–78. doi: 10.1037/0003-066x.55.1.68

Sallis, J. F., Prochaska, J. J., and Taylor, W. C. (2000). A review of correlates of physical activity of children and adolescents. *Med. Sci. Sports Exerc.* 32, 963–975. doi: 10.1097/00005768-200005000-00014

Sarstedt, M., and Mooi, E. (2019). "Cluster analysis," in *A Concise Guide to Market Research*, eds M. Sarstedt and E. Mooi (Berlin: Springer-Verlag).

Schwarzer, R. (2008). Modeling health behavior change: how to predict and modify the adoption and maintenance of health behaviors. *Appl. Psychol. Int. Rev.* 57, 1–29. doi: 10.1111/j.1464-0597.2007.00325.x

Standage, M., Gillison, F. B., Ntoumanis, N., and Treasure, D. C. (2012). Predicting students' physical activity and health-related well-being: a prospective cross-domain investigation of motivation across school physical education and exercise settings. *J. Sport Exerc. Psychol.* 34, 37–60. doi: 10.1123/jsep.34.1.37

Steinley, D. (2006). K-means clustering: a half-century synthesis. *Br. J. Math. Stat. Psychol.* 59(Pt 1), 1–34. doi: 10.1348/000711005x48266

Sturm, D. J., Bachner, J., Haug, S., and Demetriou, Y. (2020). The German basic psychological needs satisfaction in physical education scale: adaption and multilevel validation in a sample of sixth-grade girls. *Int. J. Environ. Res. Public Health* 17:1554. doi: 10.3390/ijerph17051554

Teixeira, P. J., Carraça, E. V., Markland, D., Silva, M. N., and Ryan, R. M. (2012). Exercise, physical activity, and self-determination theory: a systematic review. *Int. J. Behav. Nutr. Phys. Act.* 9:78. doi: 10.1186/1479-5868-9-78

Telama, R. (2009). Tracking of physical activity from childhood to adulthood: a review. *Obes. Facts* 2, 187–195. doi: 10.1159/000222244

Troyanskaya, O., Cantor, M., Sherlock, G., Brown, P., Hastie, T., Tibshirani, R., et al. (2001). Missing value estimation methods for DNA microarrays. *Bioinformatics* 17, 520–525. doi: 10.1093/bioinformatics/17.6.520

Vallerand, R. J. (2007). "A hierarchical model of intrinsic and extrinsic motivation for sport and physical activity," in *Intrinsic Motivation and Self-Determination in Exercise and Sport*, eds M. S. Hagger and N. L. D. Chatzisarantis (Champaign, IL: Human Kinetics), 255–279.

Van den Berghe, L., Vansteenkiste, M., Cardon, G., Kirk, D., and Haerens, L. (2012). Research on self-determination in physical education: key findings and proposals for future research. *Phys. Educ. Sport Pedagogy* 19, 97–121. doi: 10.1080/17408989.2012.732563

Van Hecke, L., Loyen, A., Verloigne, M., van der Ploeg, H. P., Lakerveld, J., and Brug, J. (2016). Variation in population levels of physical activity in European children and adolescents according to cross-European studies: a systematic literature review within DEDIPAC. *Int. J. Behav. Nutr. Phys. Act.* 13:70. doi: 10.1186/s12966-016-0396-4

van Stralen, M. M., Yildirim, M., te Velde, S. J., Brug, J., van Mechelen, W., and Chinapaw, M. J. (2011). What works in school-based energy balance behaviour interventions and what does not? A systematic review of mediating mechanisms. *Int. J. Obes.* 35, 1251–1265. doi: 10.1038/ijo.2011.68

Vansteenkiste, M., and Mouratidis, A. (2016). Emerging trends and future directions for the field of motivation psychology: a special issue in honor of Prof. Dr. Willy Lens. *Psychol. Belg.* 56, 317–341. doi: 10.5334/pb.354

Vansteenkiste, M., Niemiec, C., and Soenens, B. (2010). The development of the five mini-theories of self-determination theory: an historical overview, emerging trends, and future directions. *Adv. Motiv. Achiev.* 16(Part A), 105–165. doi: 10.1108/S0749-74232010000016A007

Vesanto, J., Himberg, J., Alhoniemi, E., and Parhankangas, J. (1999). "Self-organizing map in Matlab: the SOM toolbox," in *Proceedings of the Matlab DSP Conference*, Espoo.

Wang, L. (2017). Using the self-determination theory to understand Chinese adolescent leisure-time physical activity. *Eur. J. Sport Sci.* 17, 453–461. doi: 10.1080/17461391.2016.1276968

Welk, G. J. (1999). The youth physical activity promotion model: a conceptual bridge between theory and practice. *Quest* 51, 5–23. doi: 10.1080/00336297.1999.10484297

World Health Organization [WHO] (2018). *Global Action Plan on Physical Activity 2018–2030: More Active People for a Healthier World*. Geneva: WHO.

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3.3 Article 3

Authors: Joachim Bachner, David J. Sturm, Stephan Haug, & Yolanda Demetriou
Title: Multi-level validation of the German physical activity self-efficacy scale in a sample of female sixth-graders
Journal: BMC Public Health
Doi: 10.1186/s12889-020-09096-4

Summary:
As an example for an in-depth validation of a psychometric scale, the physical activity self-efficacy scale was translated, adapted and thoroughly validated using a multi-level approach. Data of 454 female sixth graders nested in 33 classes were included in data analysis. In contrast to the original validation study, the assumed unidimensional structure of the 8-item scale was not supported. Instead, two highly associated but distinct latent factors, representing PA self-efficacy and social support from family and friends, were differentiated. The two factors could be differentiated both on the individual and the class level. A multi-level 1x1-model including only the six items specifically measuring self-efficacy exhibited the best model fit. Reliability of the instrument was supported since internal consistencies of the complete scale and the abridged 6-item scale were good on the individual level and excellent on the class level. The two social support items exhibited low internal consistency on the individual level and excellent consistency on the class level. Criterion validity of the complete scale and the two subscales was supported by weak correlations with MVPA on the individual level and strong associations on the class level. In view of these findings, application of the multi-level approach was considered appropriate as it enabled the differentiation between self-efficacy on the individual and class level. Furthermore, estimating reliability and criterion validity separately for both levels allowed for more specific conclusions about the occurrence and effects of self-efficacy on the class level.

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Contribution:
Joachim Bachner was the leading author of the article. Yolanda Demetriou and Joachim Bachner engaged in acquisition of funding. David J. Sturm and Joachim Bachner collected

the data. Joachim Bachner developed the idea for the study. Joachim Bachner analyzed and interpreted the data, David J. Sturm and Stephan Haug lent support in data analysis. Joachim Bachner wrote the article. His co-authors contributed to manuscript revision.

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RESEARCH ARTICLE Open Access

Multi-level validation of the German physical activity self-efficacy scale in a sample of female sixth-graders

Joachim Bachner[1*], David J. Sturm[1], Stephan Haug[2] and Yolanda Demetriou[1]

Abstract

Background: The majority of children and adolescents are insufficiently physically active. Self-efficacy is considered one of the most important determinants of physical activity (PA). The purpose of this study was to validate the German version of the physical activity self-efficacy scale by means of a multi-level approach. Factorial validity, internal consistency and criterion validity were examined for the individual and the class level.

Methods: The final sample comprised 454 female sixth-graders of 33 classes. To examine the factorial validity of the translated 8-item scale, a multi-level confirmatory factor analysis was conducted with the lavaan package in R. Internal consistency was estimated with the alpha function of the psych package. Criterion validity was examined by correlating self-efficacy with moderate-to-vigorous physical activity (MVPA) assessed with accelerometers.

Results: In contrast to previous validation studies, a unidimensional structure of the scale was not supported. Instead, two highly correlated ($r_{individual} = .87$; $r_{class} = .69$) but distinct latent factors, representing PA self-efficacy and social support from family and friends, were differentiated on both the individual and class level. The best overall fit exhibited a multi-level 1×1-model, including only the six items measuring PA self-efficacy ($\chi 2 = 32.10$, CFI = .986, TLI = .976, RMSEA = .059, SRMR = .035). Internal consistencies for the complete 8-item scale and the 6-item scale were good on the individual level and excellent on the class level. For the two items measuring social support, Cronbach's alpha was low on the individual and excellent on the class level. Weak relations between self-efficacy and MVPA were found for the individual level, strong associations were found for the class level.

Conclusions: The validation speaks for the use of the abridged 6-item scale, which allows for a unidimensional assessment of PA self-efficacy. Generally, the results support the relevance of a multi-level approach, which not only differentiates between self-efficacy on the individual level and on the class level but also between the respective implications regarding reliability and criterion validity on both levels. Thereby, this study offers a rigorously validated scale and further illustrates possible consequences of the usual neglect of group-level variance in scale validation.

Keywords: Multi-level, Lavaan, Confirmatory factor analysis, Internal consistency, Criterion validity, Adolescents

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Background

Regular physical activity (PA) contributes to the prevention of chronic diseases, such as diabetes mellitus, cancer or cardiovascular diseases, and lowers the risk of premature death [1–4]. The World Health Organization (WHO) recommends children and youths aged 5 to 17 years to accumulate at least 60 min of moderate-to-vigorous physical activity (MVPA) per day, with MVPA comprising any type of activity that requires at least as much energy as is spent during ordinary walking [5]. There are two reasons why it is important for children and adolescents fulfil the PA recommendation. One would be the positive short- and middle-term effects on their health and well-being [1, 6–8]. Another reason would be a tracking effect that describes the role of adolescents' PA as a significant predictor of PA in adulthood: The more active a person is in adolescence, the higher the probability of an active lifestyle in adulthood [7, 9].

According to a questionnaire-based study, only 26% of children and adolescents in Germany aged between 3 and 17 years reach the daily 60 min of MVPA. Furthermore, less girls than boys (22.4% vs. 29%) fulfil this recommendation [10]. In addition, PA levels in this population decline with increasing age [10, 11]. A systematic review of Van Hecke et al. [12] supports the effects of gender and age on PA. Although not even the most popular device-based approaches like accelerometry offer perfectly reliable PA data [12–14], a vast majority of studies indicates that PA in adolescence does not comply with the respective recommendation [15, 16]. Moreover, the WHO recommendation is merely regarded as a minimum value. Higher MVPA levels are associated with additional health benefits [17]. Therefore, in any case it is worthwhile to promote PA from an early age.

At this point, the question arises which determinants should be focused on to increase youth's PA. Ecological models suggest that PA is affected by several interacting levels of influence ranging from policy variables, such as investments in public recreation facilities, to intrapersonal variables, including psychological constructs [18]. Among these psychological constructs, self-efficacy concerning PA is of great importance. In a review of reviews by Bauman and colleagues [19], self-efficacy was the only psychological factor consistently identified as a positive correlate and determinant of PA in children and adolescents. This finding was confirmed by an umbrella systematic review specifically focussing on psychological constructs [20]. Yet another systematic review [21] focused on the PA-related age effect and indicated that self-efficacy was one of very few constructs able to reduce the decline in PA between the age of ten and 18 years. Furthermore, two systematic reviews [22, 23] analysing intervention studies identified PA self-efficacy as the most promising mediator to increase PA.

Due to its high relevance, self-efficacy has been extensively examined in the field of PA. Over time, however, the definitions and the respective measures of youth PA self-efficacy have become more and more heterogeneous. Therefore, Voskuil and Robbins [24] conducted a concept analysis regarding the defining attributes, antecedents and consequences of the different conceptualisations. Eventually, they defined youth PA self-efficacy "as a youth's belief in his/her capability to participate in PA and to choose PA despite existing barriers" [24]. The conceptualization of self-efficacy regarding PA by Dishman and colleagues [25, 26] considers the two main points of this definition by addressing both the self-perceived confidence in the capability to be physically active as well as the recognition of barriers to PA [24].

To date, no instruments exist which are specifically constructed and appropriately validated to examine PA self-efficacy of early adolescents in secondary school in Germany. Questionnaires specifically designed for early adolescents are needed, especially regarding the wording of items. Twelve-year-olds produce a response quality worse than that of youths aged fourteen [27]. Scott [28] even argues that adolescents cannot answer properly to adult items before the age of sixteen. Furthermore, thorough validations of instruments assessing PA self-efficacy are generally scarce [29] and specific PA-related risk groups are even more rarely used in the validation of these scales [10, 12, 30].

Therefore, the purpose of this study was to validate a German version of the physical activity self-efficacy scale [26] using a sample of female sixth-graders. Because of the clustered nature of the data (students in classes), the validation was conducted in accordance with the multilevel approach described by Huang [31]. When dealing with individuals nested in groups, the use of multi-level modelling is strongly recommended [32, 33] as the assumption that individual perceptions are independent of one another cannot be maintained [34]. A violation of this assumption can lead to biased parameter estimates, false inferences regarding the psychometric properties and finally wrong conclusions about the reliability and validity of a scale [35, 36]. Therefore, factor structure and scale dimensionality were analysed by means of a multi-level confirmatory factor analysis (MCFA). Internal consistency was also estimated for both the individual and group level, respectively. Furthermore, criterion validity was tested by examining the relation of PA self-efficacy and actual PA on both levels.

Methods

Participants

The sample included 507 female sixth-graders recruited from 33 single-gender physical education (PE) classes of fifteen secondary schools in Munich. The participants

were part of the CReActivity project, a randomized controlled trial aiming to promote PA of female sixth graders [37]. Mean age was 11.61 years (SD = .55, N = 430). The girls were on average of normal weight (mean BMI = 19.49, SD = 3.68, N = 386). The number of BMI values was diminished as parts of the sample refused to be weighed. Refusal was shown by both apparently overweight and normal weight girls. The sample comprised participants from households of low, medium and high socioeconomic status (SES; mean = 49.80, SD = 15.96, N = 412). SES was assessed by asking the adolescents to name and describe their parents' current jobs. The answers were classified referring to the International Socioeconomic Index of occupational status (ISEI), which is based on the International Standard Classification of Occupation 2008 (ISCO-08) [38]. When the jobs of both parents could be classified, the job with the higher ISEI was considered (HISEI). Vague answers making a definite classification impossible, reduced the number of HISEI values.

The study was approved by the ethics commission of the Technical University of Munich (155/16 S) and the Ministry of culture and education of the state of Bavaria in Germany.

Measures

Self-efficacy

The physical activity self-efficacy scale was used to assess the girls' perceived self-efficacy to be physically active [26]. The scale contains eight items. The original items were validated in samples of sixth- and eighth-grade girls. Confirmatory factor analyses supported a unidimensional model [25, 26, 39]. Participants responded on a five point Likert-type scale ranging from 1 ("Disagree a lot") to 5 ("Agree a lot"). The scale validated here was translated into German by means of a combined translation technique including the committee approach and the pretest procedure [40, 41]. The committee comprised four bilingual experts that translated the original scale into German. The main advantage of the committee approach lies in the possibility of correcting each other quickly and directly in the case of a mistake. Since it was necessary to not only translate the items but to adapt them in order to prevent the participants from misunderstanding the meaning of the items and thus guarantee content equivalence between the original and translated scale, the committee approach was deemed more useful than the classic back-translation technique. The pretest procedure implies a pilot study, which allows the identification of potential problems before start of the main study. A sample of 161 sixth graders ($N_{female} = 71$, $N_{male} = 90$) attending the same type of school was used for pilot testing to eventually be able to provide a final version that every student can understand.

Physical activity

To assess leisure time MVPA, participants wore accelerometers (ActiGraph GT3X - wGT3X-BT) for seven consecutive days except during water-based activities. The device was placed on the right hip. Sampling rate was set to 30 Hz. Participants had to wear the device on weekdays starting at the latest on their way to school until 9 pm or until they went to bed. On weekend days, the students had to put it on as soon as they woke up until 9 pm or until they went to bed.

Procedures

Several weeks before the beginning of the data assessments, students and their parents were informed in writing about the purpose and the procedure of the assessment. Students did not participate unless they had provided a written consent form before.

Data assessments took place at the beginning of a physical education lesson. Codes were used to ensure the anonymity of the participants. Before handing out the accelerometers, the assessment team explained how to put them on. At least 25% of the students of each class received an information sheet on how to handle the accelerometers enabling them to serve as contact persons for their classmates. After the students had put on the accelerometers correctly, they filled out the questionnaire. The actual PE lesson did not start until the last student had completed the questionnaire.

Data analysis

Multi-level validation of the physical activity self-efficacy scale

As the sample examined in this study provides clustered data, the validation is based on the multi-level approach by Huang [31]. Ignoring the clustered nature of the data can lead to wrong parameter estimates, standard errors and model fits. It is recommended to account for multilevel data even if intracluster correlations (ICC) of the single manifest variables are small (e.g., ICC = 0.01) [35, 42]. In nested data, factor structures might not be the same for each level [31]. MCFA provides the opportunity to examine individual- and group-level data simultaneously. To this end, the total population covariance matrix is divided into a pooled within-group covariance matrix and a between-group covariance matrix. Thereby, both within- and between-group effects can be estimated at the same time. Huang [31] offers an R syntax to be used with the lavaan package [43] and a function for generating the required matrices based on the five MCFA steps outlined by Hox (44, Chapter 14).

In step 1, a single-level factor analysis is performed using only the pooled within-group covariance matrix. In step 2, the null model, which assumes the factor structure of step 1 for both levels, is fitted. In this step,

both the pooled within- and between-group covariance matrices are used as input. Equality constraints for the two levels are applied, meaning that factor loadings, variances and covariances for every manifest variable and latent factor are assumed to be the same for the two levels. In step 3, new group-level latent variables are introduced to estimate the variance attributed to the groups. This step is referred to as the independence model since the newly introduced group-level variables are not allowed to covary. This constraint is eliminated in step 4, the so-called saturated model. All degrees of freedom at the between-group level are now used, making it a fully saturated model. Finally, in step 5, the model that is actually hypothesized, is specified. At least one overall general factor is added for the between-group level which is defined responsible for the correlation of the latent group-level factors [31]. For every model, small negative residual variances on the class level are fixed to zero to allow the model to fully converge. This common practice is particularly required when the number of units on the group level is small and ICCs are close to zero [44].

To evaluate model fit, several fit indices were considered [45]: the χ2-likelihood ratio statistic, the comparative fit index (CFI), the Tucker-Lewis index (TLI), the root mean square error of approximation (RMSEA) and the standardized root mean square residual (SRMR). As the χ2-goodness of fit test tends to reject reasonably fitting models when applied to data of large samples, a variety of fit indices was used to estimate model fit [45]. Whereas CFI and TLI values greater than .95 indicate a good model fit, values less than or equal to .08 suggest a good model fit when RMSEA and SRMR are considered [45].

Furthermore, as fit tends to improve by including more variables in the model, parsimony is another criterion taken into account when deciding for a preferred model. Akaike's information criterion (AIC) was considered as it not only compares the fit of different models but also penalizes an increasing amount of estimated parameters [46]. The AIC is a relative fit index which is used for model comparison. Lower AIC values indicate better model fit. Eventually, the aim is to generate a model that explains as much variance as possible with as few variables as necessary. Therefore, the optimal combination of model fit and parsimony is sought [47].

Scale reliability is indicated by Cronbach's alpha. Values were calculated for both levels separately by using the alpha function of the psych package in R [48]. In case of non-positive definite matrices, alpha was calculated for the nearest positive definite matrix [49].

Criterion validity was examined by correlating self-efficacy values with the participants' MVPA values. Pearson r is indicated for both the pooled within-group correlation and the between-group correlation.

Model-based correlations were used to estimate potential relations between latent factors.

Physical activity

During the download of the PA data, the vector magnitude counts were summed over 1-s epochs (10-s epochs for GT3X because of lower memory and battery capacities). The low frequency extension filter was not used. Wear-time validation was conducted with the algorithm by Choi, Liu, Matthews and Buchowski [50]. A participant's PA data was considered valid if data of at least three weekdays and one weekend day were available with at least eight hours of wear time being required for a valid day. The wear-time validated PA data was analysed utilizing the cut points by Hänggi, Phillips and Rowlands [13] to eventually calculate the average duration of MVPA per day for each participant. The cut points by Hänggi et al. [13] were chosen because they provide a precise assessment and were validated by applying the same data sampling and processing criteria as the ones chosen for this study [51].

Results

Of the 507 participants originally included in the sample, 53 had missing values in at least one item of the physical activity self-efficacy scale. The values were missing completely at random. Additionally, the substantial sample size, the moderate interitem correlations and the acceptable proportion of missing values allowed for an available item analysis (AIA). Given these circumstances, an AIA leads to equivalent results compared with a multiple imputation analysis, which makes it unnecessary to intervene and replace missing values [52]. The participants excluded from the analysis did not differ significantly from the valid sample regarding BMI, SES, self-efficacy and MVPA. Finally, 454 sixth-graders built the final sample.

The descriptive statistics of the eight items of the physical activity self-efficacy scale are presented in Table 1. Means of the items ranged from 3.17 (*SD* =

Table 1 Descriptive statistics for the items of the physical activity self-efficacy scale (N = 454)

Item #	M	SD	Skewness	Kurtosis	ICC
1	3.83	1.06	−0.49	− 0.65	.02
2	3.36	1.35	−0.30	−1.10	.04
3	3.96	1.14	−0.92	0.03	.04
4	3.86	1.10	−0.66	− 0.30	.03
5	3.33	1.30	−0.19	−1.06	.03
6	3.64	1.21	−0.53	−0.65	−.01
7	3.71	1.10	−0.42	−0.69	−.01
8	3.17	1.30	0.00	−1.11	.01

Note. M mean; *SD* standard deviation; *ICC* intraclass correlation

1.30) to 3.96 (*SD* = 1.14). Skewness and kurtosis values were low to moderate. ICCs were small (< .05).

For the single-level one-factor model, an acceptable fit was found (model A in Table 2). Compared to model A, the null model ($\chi2 = 85.87$, CFI = .975, TLI = .975, RMSEA = .048, SRMR = .047, AIC = 10,425.47) fit better regarding the TLI and RMSEA, but fit worse when considering the CFI, SRMR and AIC. Whereas model fit did not change substantially for the independence model ($\chi2 = 75.50$, CFI = .977, TLI = .973, RMSEA = .050, SRMR = .044, AIC = 10,431.10), the fit of the saturated model differed according to the respective fit index ($\chi2 = 44.36$, CFI = .979, TLI = .942, RMSEA = .073, SRMR = .030, AIC = 10,455.96). In the last step of the algorithm outlined by Hox (44, Chapter 14) and Huang [31], model B was obtained, see Table 2. For this model, one overall general factor was added for the class level (1 × 1-model). Model B contains twice as many degrees of freedom as the single-level model A, which led to an increase of the $\chi2$ and AIC value. However, according to the CFI, TLI and RMSEA, model fit improved compared to the single-level model A. For model B, all factor loadings were significant on the individual level whereas on the class level three out of eight items exhibited significant loadings (Table 3).

For model C (2 × 2-model), a second latent factor was introduced on both levels which is modelled by items 2 (in the original version by Dishman and colleagues [26]: "I can ask my parent or other adult to do physically active things with me.") and 5 (original item: "I can ask my best friend to be physically active with me during my free time on most days."). Responses to these two items rather depend on the social environment of the early adolescents and not solely on themselves. The idea of creating a separate factor comprising these two items was further supported as they exhibited the lowest factor loadings in the single-level model A (Table 3). In line with this, their correlations with the other items were below average. Specifying two factors on each level for model C decreased the number of degrees of freedom because two additional parameters had to be estimated compared to model B. However, model C had a better model fit with respect to each index, including the AIC (Table 2). Furthermore, model C also showed a better model fit compared to its single-level counterpart ($\chi2 = 41.50$, CFI = .979, TLI = .969, RMSEA = .053, SRMR = .030, AIC = 9623.81). In model C, six out of eight items exhibited factor loadings close to or above .50 on the class level, two items had loadings lower than .40. The model-based correlation of the latent factors in model C was 0.87 on the individual level and 0.69 on the class level (Table 3).

In a final step, the items 2 and 5 were excluded to test for the unidimensional structure of a six-item scale both in a single- and multi-level analysis. Again, the multilevel model (model E) fit the data better than its single-level counterpart (model D). Furthermore, model E exhibited the best fit of all models with respect to the CFI and TLI indices (Table 2). Like in every other model, the items of model E showed significant factor loadings on the individual level. On the class level, five out of six items had loadings close to or above .50, yet only one loading was statistically significant (Table 3).

Cronbach's alpha for the eight-item scale was 0.84 on the individual level and 0.91 on the class level. In the two-factor solution, the six-item subscale exhibited an alpha value of 0.85 on the individual level and 0.90 on the class level. Cronbach's alpha values for the items 2 and 5 were 0.44 on the individual level and 0.96 on the class level, using the nearest positive definite matrix for the class level.

Average MVPA per day was 80.44 min (SD = 21.01, N = 374). The pooled within-group correlation between average MVPA per day and self-efficacy measured by the eight-item scale was 0.19 ($p < .001$, N = 345). Correlations with the six-item subscale ($r = 0.19$, $p < .001$, N = 350) and two-item subscale ($r = 0.14$, $p < .01$, N = 359) were similar. Considering the 33 classes on the group

Table 2 Fit indices for five models tested via Multilevel Confirmatory Factor Analysis

	Model				
Fit index	A: One factor, single-level, 8 items	B: One factor, multi-level, 8 items	C: Two factors, multi-level, 8 items	D: One factor, single-level, 6 items	E: One factor, multi-level, 6 items
$\chi2$	44.36	61.36	56.94	26.58	32.10
df	20	40	38	9	18
CFI	.977	.982	.984	.980	.986
TLI	.968	.975	.976	.967	.976
RMSEA	.054	.049	.047	.068	.059
SRMR	.032	.038	.035	.030	.035
AIC	9624.68	10,432.96	10,432.54	6957.92	7537.17

Note. df degrees of freedom; *CFI* comparative fit index; *TLI* Tucker-Lewis index; *RMSEA* root mean square error of approximation; *SRMR* standardized root mean square residual; *AIC* Akaike's information criterion

Table 3 Standardized factor loadings and correlations of latent factors

Model						
	A	B	C		D	E
Items	F1	F1	F1	F2	F1	F1
Individual level						
1	**.72**	**.73**	**.72**		**.72**	**.73**
2	**.45**	**.45**		**.51**	x	x
3	**.64**	**.65**	**.64**		**.65**	**.65**
4	**.66**	**.68**	**.67**		**.66**	**.66**
5	**.49**	**.49**		**.55**	x	x
6	**.61**	**.60**	**.60**		**.60**	**.60**
7	**.76**	**.76**	**.76**		**.78**	**.77**
8	**.76**	**.76**	**.76**		**.76**	**.75**
Class level						
1		**.65**	**.91**			.48
2		**.82**		**.84**		x
3		.12	.57			.58
4		.33	.49			1.03
5		**1.04**		**.96**		x
6		.30	.27			.09
7		.32	.36			**.52**
8		.17	.43			.55
$R_{individual}$ (F1, F2)			**.87**			
R_{class} (F1, F2)			.69			

Note. Values in bold are statistically significant ($p < .05$); x = item not included in the model

level, the between-group correlations of MVPA per day and self-efficacy measured by the eight-item scale was r = 0.65 (p < .001, N = 33). Correlations of MVPA with the first (r = 0.57, p < .001) and the second subscale (r = 0.59, p < .001) were comparable.

Discussion

The guidelines for PA [5] are only fulfilled by a minority of children, adolescents and adults (e.g., 12, 15). As individual PA behaviour is often sustained from adolescence to adulthood (e.g., 9), interventions trying to enhance PA of children and adolescents are of great importance. To improve young people's PA behaviour, individual self-efficacy is one of the most important determinants to focus on (e.g., 20, 21). The physical activity self-efficacy scale [26] assesses the individual self-efficacy regarding PA of adolescents and incorporates the findings of the concept analysis of Voskuil and Robbins [24].

In this study, a German version of the physical activity self-efficacy scale was validated in terms of its factorial validity, internal consistency and criterion validity. Self-efficacy does not only differ on the individual level but also on the group level. Therefore, and because the scale was validated with clustered data, analysis was conducted based on a multi-level framework [31]. This way, a mismatch between the constitution of self-efficacy and its assessment and analysis was circumvented. The physical activity self-efficacy scale can be applied to measure the construct both on the individual and the group level at the same time by applying the summary index model [53]. It suggests that the aggregated variable on the group level can be the sum or the average of a variable assessed at the individual level.

The examination of its factorial validity in this sample indicated that the physical activity self-efficacy scale not only measured PA self-efficacy with six items but also PA-related social support of family and friends with the two remaining items. The actual self-efficacy items build a highly reliable measurement. These findings applied both to the individual and class level. Furthermore, the scale provided substantial criterion validity as it contributed to the explanation of the female sixth-graders' PA, especially on the class level.

Self-efficacy in our sample was comparable to the self-efficacy of the sample of sixth-graders used to validate the original scale by Dishman and colleagues [26] in terms of the means (3.61 vs. 3.74, see Table 1). Standard deviation was almost identical (0.83 vs. 0.79), kurtosis of the items was similar (– 1.10 to 0.03 vs. -1.05 to 0.65).

The fit of the single-level one-factor model A (Table 2) was acceptable, which justified the implementation of the subsequent steps of the MCFA. The ICCs of the items did not suggest a substantial variance between the classes. The fits of the null model, independence model, and saturated model did not allow for a clear-cut inference about a statistically significant group-level variance [31, 44].

Concerning the fit indices which are less sensitive to the number of parameters to be estimated, the fit of the one-factor multi-level model B was better than the fit of the single-level model A (see Table 2). This result justifies a MCFA as it shows that there was relevant between-group variance, which should be taken into account, although the ICCs of the items were low.

The introduction of a second factor on both levels (model C) further improved model fit. Whereas six items of the physical self-efficacy scale by Dishman and colleagues [26] indeed relate to PA-related self-efficacy, the wording of the items 2 and 5 addresses the family and peers of the participant as agents providing social support for PA. This interpretation can be traced back to the original self-efficacy scale by Saunders and colleagues [54], which built the foundation for the scale validated in this study. This scale comprised the three subscales barriers, positive alternatives and support seeking, which item 2 and 5 were part of. The answers to these items mainly depend on circumstances which

cannot be fully controlled by an early adolescent. If the parents both work full time and, on top of that, are not interested in being physically active, the child lacks the means to change these circumstances. Similarly, if the best friend does not like to be active and cannot be reached within a manageable distance for a child, chances of regularly engaging in PA together are low. Thus, an actually self-efficacious adolescent can disagree with these items while agreeing with the remaining items, which refer to more personally controllable aspects and attitudes. The fact that items 2 and 5 show the lowest loadings in the single-level model A and exhibit comparatively low correlations with the remaining items indicate that this scenario occurred in a considerable number of cases. Thus, in the sample used in this study, the items selected by Dishman et al. [26] do not form a unidimensional scale. Taken together, these findings argue against the supposed unidimensional structure of the physical activity self-efficacy scale [25, 26, 39].

The sample of this study only included adolescents attending schools in the city of Munich. Living in an urban area with good infrastructure, they have good opportunities to visit their friends on their own by foot, bike or public transport. In a sample including students both from urban and rural areas, the possibilities of visiting the best friend on one's own might differ largely between classes. In this case, between-group variance specifically concerning item 5 would increase. The fact that model C fits the data better than its single-level two-factor counterpart means that even with this rather homogeneous sample, there is variance regarding both factors on the individual as well as on the class level. This again underlines the benefit of the multi-level approach used in this study. Using only a single-level approach would have led to a loss of substantial information regarding PA self-efficacy and PA social support on the class level.

Bandura [55] posited four main sources of self-efficacy. Verbal persuasion by influential others saying that one has the capabilities to master the task ahead can increase self-efficacy. The current emotional and physiological state also plays a role, as an energetic and healthy person will most likely perceive a higher self-efficacy compared to a self-conscious person dealing with a serious health condition. The two most important resources, however, are mastery and vicarious experiences. The experience of mastering a particular challenge should increase one's confidence to also master similar tasks in the future. Vicarious experiences could finally explain the finding that the two latent factors PA self-efficacy and PA social support are highly correlated ($r \geq 0.69$, Table 3). It can be assumed that people who regularly provide social support for PA are physically active themselves, which is implied in the wording of items 2 and 5. Thus, they can serve as role models for a healthy PA behaviour. The concept of vicarious experience [55] suggests that if a person observes another person performing successfully, it can enhance the confidence in the own ability to succeed in the same task, especially when the person being observed is deemed similar to oneself. This can lead to the effect that an adolescent's PA behaviour influences his/her best friend and vice versa. Hence, vicarious experience [55] might mediate the association of PA social support and PA self-efficacy. Furthermore, the attraction paradigm [56] proclaims that perceived similarity to a peer is a major factor that determines whether a relationship turns into a close friendship or not. Taken together, it can be assumed that close friends often think the same way about being physically active because their similarity led to their friendship in the first place [56] and vicarious experiences help to further assimilate to each other in terms of PA self-efficacy [55]. This could explain the correlation of item 5 with the six items assessing PA self-efficacy.

Since the perceived similarity between observer and role model plays a major role in vicarious experiences [55] and adolescents normally perceive their parents as being less similar to them as their friends, it is unlikely that vicarious experiences explain the association of parental PA support and children's PA self-efficacy. Instead, parental PA support might have a direct positive effect on PA self-efficacy [57]. In sixth-graders, particularly parents' emotional and instrumental social support have an effect on the adolescents' PA self-efficacy [58]. These findings could explain why responses to item 2 correlate highly with self-efficacy.

Given these points, although previous validations of the physical activity self-efficacy scale supported a unidimensional model [25, 26, 39], the present study shows the need to distinguish a second factor assessing PA-related support by parents and peers with regard to statistical and conceptual aspects. Additionally, it is worth mentioning that the previous single-level validation studies revealed factor loadings below 0.40 for at least one item [25, 39]. As it has been criticized elsewhere [30], this indicates a lack of scale homogeneity and questions a unidimensional structure, however, these results have not been discussed appropriately [25, 39].

Finally, if the actual goal is to measure early adolescents' PA self-efficacy, items 2 and 5 should be excluded from the data assessment, as other researchers have done [59]. Consequently, specifying a one-factor structure on both levels after excluding the items 2 and 5 led to the best overall model fit (model E), especially with respect to the CFI and TLI indices. Furthermore, the comparison between the single-level and multi-level analysis of this shortened version of the physical activity

self-efficacy scale [26] also supported the consideration of between-group differences.

Reliability was estimated for the individual and the class level separately [31]. Cronbach's alpha for the eight-item scale was good on the individual level and excellent on the class level [60]. Cronbach's alpha is positively associated with the number of items [61]. Alpha values for the shorter six-item subscale representing PA self-efficacy, however, were not diminished, which speaks for an even higher internal consistency of this sub-group of items compared to the complete scale. Cronbach's alpha for the two-item support factor was low on the individual level and excellent on the class level. Thus, the association of support from family and peers becomes less ambiguous when the nesting of students in classes is considered. Composite reliability was also estimated to make sure that reliability was not underestimated when using Cronbach's alpha [61, 62]. Differences between the two methods were marginal. Higher reliability values on the group level were expected since reliability tends to increase and measurement error tends to decrease when measures are aggregated across students within the same classes [63].

Likewise, the use of aggregated measures on the class level normally affects factor loadings and correlations to be higher on this level [63]. This assumption was only partially met (Table 3). Although the number of classes included in this study fulfils the minimum amount for conducting a MCFA [64], it still might have reduced the group-level factor loadings and model-based correlations between the latent factors.

Finally, the scores of the complete scale and its subscales were correlated with actual PA to evaluate the criterion validity. The average MVPA level was in line with a systematic review including 36 studies mainly conducted in Europe and North America [65]. However, average MVPA was higher than in previous German studies. It is unlikely that the sample in this study exhibits an unrepresentatively good PA behaviour. In fact, the differences to previous German studies can be explained by the use of different PA measurement instruments (self-report questionnaires vs. accelerometers) and different sampling and analysis decisions concerning the accelerometer data, which have a severe impact on the estimated PA values [10, 14, 51, 66]. In this study, a high resolution was chosen, leading to the most accurate PA estimates possible [13, 50, 51], which at the same time implicated higher MVPA values than usually found in Germany. The participants' scores on the complete eight-item scale and the two subscales revealed a significant positive relation to their actual PA. This is in line with previous research emphasising the role of self-efficacy as an important determinant of healthy PA behaviour of children and adolescents (e.g., 19, 20). The correlations were clearly higher on the class level, which again justifies the multi-level approach and underlines the differentiation between self-efficacy on the individual and on the group level. Furthermore, this could favour the incremental value of multi-level modelling regarding the association between self-efficacy and PA. Considering that the construct of PA self-efficacy is by definition closely connected to the actual PA behaviour [24], the correlation between PA self-efficacy and actual PA is rather low in the majority of studies (e.g., 20, 21, 22). The higher reliability and lower measurement error of the aggregated class-level measures used here, could contribute to detecting correlation coefficients that are closer to the respective true value [63].

Strengths and limitations

The main strength of this study lies in the application of a multi-level approach to clustered data of students nested in classes. Even though the ICCs suggested a negligible variance on the class level [35, 42], multi-level models consistently exhibited a better fit and thus are more suited to depict the actual data. By means of the multi-level approach, it was shown that reliability and criterion validity of the validated scale can differ significantly between the individual and the class level.

The findings should be verified in a more diverse sample comprising girls and boys of different age and from both rural and urban background. Further research on the construct or, more specifically, the physical activity self-efficacy scale [26] should include a larger number of classes on the group level and also more students per class. Measurement invariance across time should be tested in a longitudinal design with a sample that is not exposed to any intervention. Additionally, validation of the scale in a sample with low PA would further support the applicability of the scale to adolescents with diverse activity levels.

Conclusions

Thoroughly validated scales with good psychometric criteria are essential for sound evaluations of cross-sectional studies and intervention programmes. This multi-level validation suggests that the German version of the physical activity self-efficacy scale [26] not only measures PA self-efficacy but also PA-related social support by family and friends. The two latent factors are highly correlated on both levels, but statistically and conceptually distinguishable. Therefore, it should be discussed if the scale should continue to be considered unidimensional.

This study argues for the validation of psychometric scales using a multi-level approach because substantial

information regarding class-level self-efficacy would have been lost by applying a single-level validation.

It is recommended to exclude the social support items from data assessments to have a highly reliable and valid measurement instrument for individual- and class-level PA self-efficacy.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s12889-020-09096-4.

Additional file 1. validation data; description: minimal dataset necessary to replicate the analysis.

Abbreviations

AIC: Akaike's information criterion; BMI: Body mass index; CFI: Comparative fit index; df: degrees of freedom; HISEI: Highest International Socioeconomic Index of occupational status; ICC: Intracluster correlation; ISCO: International Standard Classification of Occupation; ISEI: International Socioeconomic Index of occupational status; M: Mean; MCFA: Multi-level confirmatory factor analysis; MVPA: Moderate-to-vigorous physical activity; PA: Physical activity; PE: Physical education; RMSEA: Root mean square error of approximation; SD: Standard deviation; SES: Socioeconomic status; SRMR: Standardized root mean square residual; TLI: Tucker-Lewis index; WHO: World Health Organization

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Authors' contributions

JB collected, analysed and interpreted the data and drafted the manuscript. DJS also collected data and contributed to the data analysis. SH lent substantial support in the analysis and interpretation of the data. YD supervised the cooperation of the authors and revised the manuscript critically for important intellectual content. All authors read and approved the final manuscript.

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Availability of data and materials

All data analysed during this study are included in the supplementary information files of this article.

Ethics approval and consent to participate

The study was approved by the ethics commission of the Technical University of Munich (155/16 S) and the Ministry of culture and education of the state of Bavaria in Germany.
Students did not participate if they had not provided a consent form signed by them and their parents before.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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References

1. Granger E, Di Nardo F, Harrison A, Patterson L, Holmes R, Verma A. A systematic review of the relationship of physical activity and health status in adolescents. Eur J Public Health. 2017;27(suppl_2):100–6.
2. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet. 2012;380(9838):219–29.
3. McKinney J, Lithwick DJ, Morrison B, Nazzari H, Isserow SH, Heilbron B, et al. The health benefits of physical activity and cardiorespiratory fitness. Br Columbia Med J. 2016;58(3):131–7.
4. Warburton DER, Nicol CW, Bredin SSD. Health benefits of physical activity: the evidence. Can Med Assoc J. 2006;174(6):801–9.
5. World Health Organization. Global action plan on physical activity 2018–2030: more active people for a healthier world. Geneva: World Health Organization; 2018.
6. Archer T. Health benefits of physical exercise for children and adolescents. J Novel Physiotherapies. 2014;04(02):203–5.
7. Hallal PC, Wells JC, Reichert FF, Anselmi L, Victora CG. Early determinants of physical activity in adolescence: prospective birth cohort study. BMJ. 2006;332(7548):1002–7.
8. Loprinzi PD, Cardinal BJ, Loprinzi KL, Lee H. Benefits and environmental determinants of physical activity in children and adolescents. Obesity Facts. 2012;5(4):597–610.
9. Telama R. Tracking of physical activity from childhood to adulthood: a review. Obesity Facts. 2009;2(3):187–95.
10. Finger JD, Varnaccia G, Borrmann A, Lange C, Mensink G. Körperliche Aktivität von Kindern und Jugendlichen in Deutschland – Querschnittergebnisse aus KiGGS Welle 2 und Trends. J Health Monit. 2018;3(1):24–31.
11. Dumith SC, Gigante DP, Domingues MR, Kohl HW 3rd. Physical activity change during adolescence: a systematic review and a pooled analysis. Int J Epidemiol. 2011;40(3):685–98.
12. Van Hecke L, Loyen A, Verloigne M, van der Ploeg HP, Lakerveld J, Brug J, et al. Variation in population levels of physical activity in European children and adolescents according to cross-European studies: a systematic literature review within DEDIPAC. Int J Behav Nutr Phys Act. 2016;13(1):70.
13. Hänggi JM, Phillips LR, Rowlands AV. Validation of the GT3X ActiGraph in children and comparison with the GT1M ActiGraph. J Sci Med Sport. 2013;16(1):40–4.
14. Migueles JH, Cadenas-Sanchez C, Tudor-Locke C, Löf M, Esteban-Cornejo I, Molina-Garcia P, et al. Comparability of published cut-points for the assessment of physical activity: implications for data harmonization. Scand J Med Sci Sports. 2019;29(4):566–74.
15. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U. Global physical activity levels: surveillance progress, pitfalls, and prospects. Lancet. 2012;380(9838):247–57.
16. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1.6 million participants. Lancet Child Adolesc Health. 2020;4(1):23–35.
17. World Health Organization. Global recommendations on physical activity for health. Geneva: World Health Organization; 2010.
18. Sallis JF, Owen N, Fisher E. Ecological Models of Health Behavior. In: Glanz K, Rimer BK, Viswanath K, editors. Health behavior and health education: Theory, research, and practice: Jossey-Bass; 2008. p. 465–85.
19. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical activity: why are some people physically active and others not? Lancet. 2012;380(9838):258–71.
20. Cortis C, Puggina A, Pesce C, Aleksovska K, Buck C, Burns C, et al. Psychological determinants of physical activity across the life course: a "DEterminants of DIet and physical ACtivity" (DEDIPAC) umbrella systematic literature review. PLoS One. 2017;12(8):e0182709.
21. Craggs C, Corder K, van Sluijs EM, Griffin SJ. Determinants of change in physical activity in children and adolescents: a systematic review. Am J Prev Med. 2011;40(6):645–58.
22. van Stralen MM, Yildirim M, te Velde SJ, Brug J, van Mechelen W, Chinapaw MJ. What works in school-based energy balance behaviour interventions

and what does not? A systematic review of mediating mechanisms. Int J Obes. 2011;35(10):1251–65.
23. Lubans DR, Foster C, Biddle SJ. A review of mediators of behavior in interventions to promote physical activity among children and adolescents. Prev Med. 2008;47(5):463–70.
24. Voskuil VR, Robbins LB. Youth physical activity self-efficacy: a concept analysis. J Adv Nurs. 2015;71(9):2002–19.
25. Motl RW, Dishman RK, Trost SG, Saunders RP, Dowda M, Felton G, et al. Factorial validity and invariance of questionnaires measuring social-cognitive determinants of physical activity among adolescent girls. Prev Med. 2000;31(5):584–94.
26. Dishman RK, Hales DP, Sallis JF, Saunders R, Dunn AL, Bedimo-Rung AL, et al. Validity of social-cognitive measures for physical activity in middle-school girls. J Pediatr Psychol. 2010;35(1):72–88.
27. Borgers N, de Leeuw E, Hox J. Children as respondents in survey research: cognitive development and response quality 1. Bull Sociol Methodol. 2000; 66(1):60–75.
28. Scott J. Children as respondents: methods for improving data quality. In: Lyberg L, Biemer P, Collins M, De Leeuw E, Dippo C, Schwarz N, et al., editors. Survey Measurement and Process Quality. New York: Wiley, Inc.; 1997. p. 331–50.
29. Brown H, Hume C, Chin AM. Validity and reliability of instruments to assess potential mediators of children's physical activity: a systematic review. J Sci Med Sport. 2009;12(5):539–48.
30. Dewar DL, Lubans DR, Morgan PJ, Plotnikoff RC. Development and evaluation of social cognitive measures related to adolescent physical activity. J Phys Act Health. 2013;10(4):544–55.
31. Huang F. Conducting multilevel confirmatory factor analysis using R; 2017.
32. Feltz DL, Short SE, Sullivan PJ. Self-efficacy in sport. Champaign: Human Kinetics; 2008.
33. Ede A, Hwang S, Feltz DL. Current directions in self-efficacy research in sport. Revista Iberoamericana de Psicología del Ejercicio y el Deporte. 2011; 6(2):181–201.
34. Huang FL, Cornell DG, Konold T, Meyer JP, Lacey A, Nekvasil EK, et al. Multilevel factor structure and concurrent validity of the teacher version of the authoritative school climate survey. J Sch Health. 2015;85(12):843–51.
35. Julian MW. The consequences of ignoring multilevel data structures in nonhierarchical covariance modeling. Struct Equ Model Multidiscip J. 2001; 8(3):325–52.
36. Dedrick R, Greenbaum P. Multilevel confirmatory factor analysis of a scale measuring interagency collaboration of Children's mental health agencies. J Emot Behav Disord. 2011;19:27–40.
37. Demetriou Y, Bachner J. A school-based intervention based on self-determination theory to promote girls' physical activity: study protocol of the CReActivity cluster randomised controlled trial. BMC Public Health. 2019; 19(1):519.
38. Ganzeboom H. A new International Socio-Economic Index (ISEI) of occupational status for the International Standard Classification of Occupation 2008 (ISCO-08) constructed with data from the ISSP 2002–2007. Lisbon: Annual Conference of International Social Survey Programme; 05/01/2010; 2010.
39. Dishman RK, Motl RW, Saunders RP, Dowda M, Felton G, Ward DS, et al. Factorial invariance and latent mean structure of questionnaires measuring social-cognitive determinants of physical activity among black and white adolescent girls. Prev Med. 2002;34(1):100–8.
40. Brislin RW. Back-translation for cross-cultural research. J Cross-Cult Psychol. 1970;1(3):185–216.
41. Cha ES, Kim KH, Erlen JA. Translation of scales in cross-cultural research: issues and techniques. J Adv Nurs. 2007;58(4):386–95.
42. Musca SC, Kamiejski R, Nugier A, Méot A, Er-Rafiy A, Brauer M. Data with hierarchical structure: impact of intraclass correlation and sample size on type-I error. Front Psychol. 2011;2:74.
43. Rosseel Y. lavaan: An R Package for Structural Equation Modeling. J Stat Software. 2012;1(2):2012.
44. Hox JJ. Multilevel analysis: techniques and applications. 2nd ed. New York: Routledge/Taylor & Francis Group; 2010.
45. Hu L, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. Struct Equ Model Multidiscip J. 1999;6(1):1–55.
46. Korner-Nievergelt F, Roth T, von Felten S, Guélat J, Almasi B, Korner-Nievergelt P. Model Selection and Multimodel Inference. Bayesian Data Analysis in Ecology Using Linear Models with R, BUGS, and STAN. Amsterdam: Academic Press; 2015. p. 175–96.
47. Preacher KJ, Zhang G, Kim C, Mels G. Choosing the optimal number of factors in exploratory factor analysis: a model selection perspective. Multivar Behav Res. 2013;48(1):28–56.
48. Revelle WR. psych: Procedures for personality and psychological research; 2017.
49. Higham N. Computing the nearest correlation matrix - a problem from finance. IMA J Numer Anal. 2002;22:329–43.
50. Choi L, Liu Z, Matthews CE, Buchowski MS. Validation of accelerometer wear and nonwear time classification algorithm. Med Sci Sports Exerc. 2011;43(2): 357–64.
51. Migueles JH, Cadenas-Sanchez C, Ekelund U, Delisle Nystrom C, Mora-Gonzalez J, Lof M, et al. Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations. Sports Med. 2017;47(9):1821–45.
52. Parent MC. Handling item-level missing data: simpler is just as good. Couns Psychol. 2013;41(4):568–600.
53. Chen G, Mathieu JE, Bliese PD. A framework for conducting multi-level construct validation. Multi-level Issues Organ Behav Process. 2015;3:273–303.
54. Saunders RP, Pate RR, Felton G, Dowda M, Weinrich MC, Ward DS, et al. Development of questionnaires to measure psychosocial influences on children's physical activity. Prev Med. 1997;26(2):241–7.
55. Bandura A. Self-efficacy: the exercise of control. New York: W H Freeman & Co.; 1997.
56. Byrne D. The attraction paradigm. New York: Academic press; 1971.
57. Trost SG, Sallis JF, Pate RR, Freedson PS, Taylor WC, Dowda M. Evaluating a model of parental influence on youth physical activity. Am J Prev Med. 2003;25(4):277–82.
58. Peterson MS, Lawman HG, Wilson DK, Fairchild A, Van Horn ML. The association of self-efficacy and parent social support on physical activity in male and female adolescents. Health Psychol. 2013;32(6):666–74.
59. Voskuil VR, Pierce SJ, Robbins LB. Comparing the psychometric properties of two physical activity self-efficacy instruments in urban, adolescent girls: validity, measurement invariance, and reliability. Front Psychol. 2017;8:1301.
60. Kubinger KD. Psychologische Diagnostik: Theorie und Praxis psychologischen Diagnostizierens (2., überarb. und erw. Aufl.). Göttingen: Hogrefe; 2009.
61. Tang W, Cui Y, Babenko O. Internal consistency: do we really know what it is and how to assess it? J Psychol Behav Sci. 2014;2(2):205–20.
62. Raykov T. Behavioral scale reliability and measurement invariance evaluation using latent variable modeling. Behav Ther. 2004;35(2):299–331.
63. Byrne BM. Structural equation modeling with Mplus: basic concepts, applications, and programming. New York: Routledge/Taylor & Francis Group; 2012.
64. Kreft I, de Leeuw J. Introducing multilevel modeling. Thousand Oaks: Sage Publications, Inc; 1998.
65. Brooke HL, Corder K, Atkin AJ, van Sluijs EM. A systematic literature review with meta-analyses of within- and between-day differences in objectively measured physical activity in school-aged children. Sports Med. 2014;44(10): 1427–38.
66. Konstabel K, Veidebaum T, Verbestel V, Moreno LA, Bammann K, Tornaritis M, et al. Objectively measured physical activity in European children: the IDEFICS study. Int J Obes. 2014;38(Suppl 2):S135–43.

Publisher's Note

4 General Discussion

Besides providing insights into female sixth graders' PA behaviour and its psychosocial determinants, the presented studies put a strong focus on the application of recent methodological approaches and the discussion of their advantages and implications. It was shown that PA behaviour of the participants was on a good level when using the WHO recommendation of a daily average of 60 minutes MVPA as a benchmark (Bull et al., 2020). However, SB was clearly worse since the girls averaged more than seven hours of sedentary time even on days without school. Considering methodological aspects, it has to be highlighted that participants' PA scores would have been lower and SB scores would have been even higher if the accelerometer sampling and processing criteria used in previous German and international large-scale studies had been applied in this study as well (e.g., Konstabel et al., 2014; Ruiz et al., 2011). Furthermore, using a person-oriented approach, it was illustrated that PA behaviour is driven by simultaneous coexistence and interaction of several psychosocial determinants within an individual (Bergman & Lundh, 2015; Lindwall et al., 2017). Superordinate profiles of psychosocial PA determinants were in line with previous assumptions (Ryan & Deci, 2000). However, subgroups could be detected that to some extent conflicted with theoretical foundations. Thus, thanks to the application of a person-oriented approach, insights into the interactions of psychosocial resources driving accelerometer-measured PA behaviour of adolescents were provided for the first time. In addition, recent recommendations in the examination of psychometric criteria of self-report scales with multi-level data were implemented in a validation study of the translated and adapted German physical activity self-efficacy scale (Dishman et al., 2010; Huang, 2017).

4.1 Measurement of Physical Activity and Sedentary Behaviour of Children and Adolescents by Means of Accelerometry

There are many reasons for the popularity of accelerometers in the assessment of PA and SB in children and adolescents. When searching for a good compromise between feasibility on the one hand and accuracy and offered detail of the results on the other hand, accelerometers are probably the best choice (Dollman et al., 2009; Loprinzi & Cardinal, 2011). Until recently, accelerometers were assigned to the so-called objective measures (e.g., Ruiz et al., 2011). Nowadays, accelerometry is usually described as a device-based method. The term 'objective' suggests an unbiased measurement free of any influences that would exclusively measure actual PA behaviour. However, this assumption was never fulfilled by accelerometer assessments. Instead, one has to be aware of the fact that the variety of different sampling and processing criteria in accelerometry that is offered to the

researcher rather caused problems than it would have strengthened empirical findings (Migueles et al., 2017; Migueles et al., 2019). Different decisions regarding, for instance, wear-time validation algorithms, epoch lengths and activity cut points that are taken by different researchers, lead to the issue that estimated PA and SB scores of the respective study samples can hardly be compared. If the choice of different criteria in different studies had always been for the benefit of increasing measurement accuracy in the respective analyses, i.e., choosing criteria that are most appropriate for the characteristics of the examined sample, deficits in comparability would become irrelevant. However, choices of sampling and processing criteria were many times simply based on what had been done before by other researchers in previous studies (e.g., Esteban-Cornejo et al., 2014). This way, comparability was preferred over accuracy, although researchers actually had accelerometers offering features for high-accuracy measurements available. Thus, although a great number of studies using accelerometers has been conducted, it has to be stated that large-scale studies offering accurate results regarding levels and patterns of PA and SB are lacking. This leads to further consequences. The evaluation if a construct is a determinant of PA or whether an intervention programme could significantly improve PA behaviour of the participants are less influenced by inaccurate PA measurements since the respective calculations are based on changes in the respective variables. For example, in the evaluation of an intervention effect, biased pre-test values are compared with post-test values that are biased in the same manner. This means that the reported absolute PA levels are indeed inaccurate, the validity of the comparison across time points, however, is less affected. With regard to guidelines on PA and SB, consequences are more serious. PA guidelines are published to inform about the PA level necessary to evoke health benefits. For the development of these guidelines, it is referred to existing studies examining the association between PA levels and health parameters. These studies have used self-report measures and also accelerometers (Bull et al., 2020; Troiano, Stamatakis, & Bull, 2020). Since these measurement instruments or the respective analyses imply severe biases leading to inaccurate PA scores, it may be questioned if the reported associations between PA and health parameters are valid, and thus if the recommended PA guidelines are appropriate.

Thus, further studies assessing PA and SB of children and adolescents have to be conducted which adhere to recent recommendations in sampling and processing of accelerometer data and will finally lead to results that are more accurate. Additionally, a lot of data assessed by accelerometry can be re-examined since only device placement, i.e., accelerometer worn on the hip or the wrist, and sampling frequency must be decided a priori (Migueles et al., 2017). The remaining decisions can be changed over and over after the measurements and respective results can be compared (e.g., Vanhelst et al., 2014). To

address the limitations implied in accelerometer assessments, like the inability or deficits in measuring water-based and stationary activities, measurement instruments should be combined to compensate for the respective limitations (Nigg et al., 2020). For example, participants should keep an activity diary at least referring to the occasions when the accelerometer could not be worn (Buchheit, Platat, Oujaa, & Simon, 2007).

4.2 Examination of Physical Activity Behaviour of Children and Adolescents by Means of the Person-Oriented Approach

The theories presented in section 1.4.1 exhibit large differences in terms of their composition, scope or settings and foremost in the PA determinants they comprise (Rhodes et al., 2019). However, with regard to the fundamental approach in their development, these theories have some crucial aspects in common. They were created deductively and, most importantly, they conceive health behaviour as a rather stable phenomenon, thus proposing differences between individuals but not within individuals (Dunton, 2017). The potential influence of time is neglected as the presented theories suggest inferences about the predictive power of constructs based on the average level of a sample in these constructs, rather than incorporating time-variant concepts like fluctuation or stability. Therefore, these theories are more suitable for health behaviours that may occur or are required occasionally, thus limited-occurrence behaviours such as vaccinations. Since repeated-occurrence health behaviours like regular PA naturally imply the concept of time, the presented theories are less suited for their explanation or promotion (Dunton, 2017). This perception is empirically supported as the power of these traditional and mostly used theories in PA explanation and promotion is small (Rhodes & Dickau, 2012; Rhodes et al., 2019).

The traditional variable-based approach consequently implements the mindset behind these theories into study design and data analysis by following the assumption that a sample's average score in a given construct measured at certain time points may be used to draw inferences about the predictive power of this construct with regard to a repetitive behaviour like PA (Bechter et al., 2018; Dunton, 2017). The person-oriented approach, in contrast, follows a more idiographic mindset in that it not only acknowledges the intraindividual coexistence and interactions of several factors affecting PA behaviour but also provides insights into the momentary level of resources of a given person in terms of PA (Dunton, 2017; Lindwall et al., 2017). In studies evaluating the effect of an intervention programme, the baseline PA level is usually taken account of since an increase in PA of a previously active sample is more difficult to achieve than a PA increase in a usually inactive sample with more room for improvement (Rhodes et al., 2017). However, the individual baseline levels in potential determinants of PA are less considered and discussed, which

might also be a reason for the inconsistent findings of systematic reviews examining correlates and determinants of PA.

Although the declared goal of these systematic reviews and, in particular, reviews of reviews is to synthesize the differences in existing evidence on a given topic (Craggs et al., 2011), there is only little agreement in the findings of the reviews presented in chapter 1.4.2 (Bauman et al., 2012; Biddle et al., 2011; Craggs et al., 2011; Sterdt et al., 2014; Uijtdewilligen et al., 2011). Reviews focused on the determinants of PA could hardly confirm the constructs that had been established as correlates of PA in the respective reviews. This circumstance may not be surprising, as determinants simply play a different role with regard to PA behaviour than correlates do (Baranowski et al., 1998). However, it may cause some concerns that reviews which actually follow the same purpose come to different conclusions regarding relevant correlates or determinants of PA, respectively. These differences are a product of several aspects. The reviews can differ in their search strategy (e.g., searched databases; time of publication of the studies) or inclusion and exclusion criteria. Different decisions in these aspects lead to different studies being included in the reviews. The studies included in a given review indeed assess the same constructs according to their denomination. However, the constructs might be defined differently and/or measured by use of different scales, and thus in fact represent slightly different latent constructs. Additionally, different reviews may apply different standards in terms of the level of evidence that has to be reached for a construct to be classified as a consistent correlate or determinant, respectively. Thus, in the end, different systematic reviews might follow different approaches in the evidence synthesis of partially different included studies that measure a given construct in slightly different ways, which may finally lead to different evaluations whether a construct is a relevant correlate or determinant for PA and SB, respectively. However, even if these aspects are given full consideration, the remaining differences are still striking, so that there must be more aspects that might have been overlooked too often. This is the point where specific sample characteristics of the studies included in the reviews might come into play and contribute to the explanation of the inconsistencies regarding which constructs are considered as relevant determinants of change in PA.

Within the variable-based approach, moderator analyses represent a first step in considering specific sample characteristics in the examination of PA correlates and determinants (Bauman, Sallis, Dzewaltowski, & Owen, 2002). The person-oriented approach, however, may explain some of the inconsistencies of systematic reviews in more detail and might at the same time contribute to the design of more effective intervention programmes, which would also provide more exact data for research about PA determinants. Person-oriented analyses do not only identify how PA is typically determined

within an individual, like it was done by means of the SOM analysis in CReActivity. It also provides insights into the momentary potentials and needs of a given person (Bechter et al., 2018; Gut et al., 2020; Lindwall et al., 2017). It is able to identify for distinct subgroups of individuals whether the potential of a PA determinant is exhausted since the profile already exhibits high scores on this variable. In this case, there would be no potential for this construct to be a mediator of change in PA (Baranowski et al., 1998; Sallis & Owen, 1999). On the other hand, person-oriented analyses can identify the respective constructs for each profile that offer room for enhancement, and thus serve as potential determinants of change providing that they can be successfully targeted by appropriate behaviour change techniques within the intervention. Moreover, person-oriented analyses do not only detect level effects. The point when person-oriented approaches have the highest incremental value over variable-based approaches is when shape effects come into play (Lindwall et al., 2017; Morin & Marsh, 2015). Based on the identification of shape effects, results suggest which combinations of levels in different determinants lead to the best outcome. Thus, the pursuit of appropriate behaviour change techniques may not only be based on insights into deficits of a profile in certain determinants. An example of a shape effect was found by the SOM analysis in the CReActivity sample. Moderate scores on external regulation in combination with high levels in autonomous regulation could only lead to highest MVPA values if introjected regulation was high as well. These more unique and partially atheoretical profiles are not captured by theoretical models and thus are of incremental value over and beyond theoretical assumptions (Lindwall et al., 2017). This argues for the use of a rather inductive, explorative approach as a starting point for tailored interventions that specifically respond to the deficits of an identified group of individuals (Dunton, 2017; Gut et al., 2020; Rhodes et al., 2019). If the intervention components are designed in a way that matches the needs and deficits of the respective profiles, changes in PA-related resources and thus movement of an individual to a more motivated and active profile can be initiated (Emm-Collison et al., 2020). Studies in adult populations have shown that movements between motivational profiles regarding PA are common and thereby support the relevance of the time concept in PA research. An encouraging finding was that especially individuals of profiles characterized by mostly controlled motivation were more likely to move between profiles, which shows that motivational resources of an individual are not immutable (Emm-Collison et al., 2020).

Thus, it has to be discussed whether it is a worthwhile goal to try and find determinants of PA by conducting systematic reviews, if the true determinants that can in fact be a mediator of PA increase are to some extent different for each sample and even for potential subgroups within a given sample. This would mean that while trying to find the determinants that are of general relevance for a population could lead researchers to move

further and further away from the truth as there might be no determinants that might equally help every sample without taking account of their momentary resources and needs (Dunton, 2017).

4.3 Future Research Perspectives

Since physical inactivity and high SB can lead to severe health issues (Biswas et al., 2015; Granger et al., 2017; van der Ploeg & Hillsdon, 2017), a parallel between the explanation of PA and a visit to the doctor might be drawn. If a patient suffering from knee pain turns to a doctor, the doctor is expected to conduct a thorough diagnosis, for example by asking the patient when the pain occurs the most or whether there are situations when there is less pain. Afterwards, the doctor might even use imaging techniques to examine the structures inside of the knee in order to identify the exact origin of the pain. In any case, the patient would be surprised and probably disappointed, if the doctor would simply prescribe an ointment saying that this would help everybody without asking the patient about his personal experiences and symptoms. Nevertheless, in some cases, the doctor might even be successful with this kind of treatment as the ingredient in the ointment coincidentally fits to the causes of the knee pain of some patients. The vast majority of patients, however, will not experience a pain relief since their knee pain has a different origin. Fortunately, in the context of disease treatment, the prevailing notion of ‘personalized medicine’ stipulates that the unique molecular, physiological or behavioural characteristics of patients have to be responded to by means of interventions that are specifically tailored to their respective characteristics (Goetz & Schork, 2018). However, this notion has not yet been consistently applied in the explanation and promotion of PA, or more precisely, in the treatment of physical inactivity. The power of deductive theories in the explanation of PA behaviour is small, ‘one-size-fits-all’ interventions designed with regard to these theories and respective variable-based systematic reviews are rarely successful. Therefore, instead of designing more and more large-scale intervention programmes that, although focusing on different determinants, are still based on the same general approach, promising alternatives need to be sought. In line with the presented person-oriented approach, a promising compromise could be to prepare an intervention programme which is based on a specific theory in terms of the variables being focused, but at the same time leaves researchers the chance to adapt the intervention components and behaviour change techniques to the respective profiles identified via person-oriented analysis of the baseline scores. Like this, the idiographic needs of the participants can be incorporated into the final design of the intervention (Dunton, 2017; Rhodes et al., 2019).

An advancement of this idea represents the use of mobile technologies for ecological momentary assessment (EMA; Shiffman, Stone, & Hufford, 2008). By means of

EMA prompts on smartphones, real-time self-reports about potential psychosocial determinants of PA can be assessed several times per day. Afterwards, the association of current levels of psychosocial resources and PA can be examined (Dunton, 2017). This approach can be classified as an advancement of the person-oriented approach, as not only the idiographic needs of an individual are assessed cross-sectionally, but even individual changes in idiographic resources are illustrated. Classifying the different approaches on a continuum reflecting the detail of individual insights, the variable-based approach represents step one since it aims to find determinants that are assumed to be relevant for everybody. Based on cross-sectional interindividual comparisons, the person-oriented approach tries to identify the needs and potential determinants of an individual at a given point of time and therefore represents step two. EMA represents step three, as intraindividual fluctuations in personal needs and resources, i.e., deviations from a participant's personal average, are identified and their occurrence at several points of time is examined (Dunton, 2017). Therefore, EMA highly acknowledges that determinants of PA do not only differ between individuals but are subject to intraindividual change, even during the course of a day. A recent EMA study with adult participants could show that PA intentions higher than average for a given participant predicted a subsequent increase in MVPA in the following two hours. Increases in MVPA, however, only occurred if current PA self-efficacy levels were higher than average for the participant as well (Pickering et al., 2016). Thus, these findings reflect typical shape effects which can be found using a person-oriented approach like SOM. However, by applying EMA the findings feature an even higher time-related resolution due to repeated momentary assessments. Furthermore, the participants who exhibited greater fluctuation in intentions and self-efficacy were the ones with the highest overall MVPA levels (Pickering et al., 2016). Again, this underlines the existence and the potential of intraindividual changes in PA determinants. The relations between time-varying determinants and PA levels can eventually build the basis for just-in-time adaptive interventions (Nahum-Shani, Hekler, & Spruijt-Metz, 2015). These are designed according to gathered insights about when, where and how intervention components like activity prompts should be delivered to achieve a maximal effect on PA.

To have highly valid assessments on both sides of the examined associations, not only potential determinants should be measured with a high resolution but also measurement of PA behaviour should follow the recommendations presented above (Migueles et al., 2017). Additionally, SB should be considered as well to expand previous evidence on determinants of SB (Uijtdewilligen et al., 2011).

5 Conclusion

The studies presented in this work combine insights into adolescent PA and SB levels and patterns with findings about PA determinants and the implications and advantages of recent methodological approaches in the respective topics. It is shown that different decisions in sampling and processing of accelerometer data imply major effects on reported PA and SB levels and patterns. Due to the implications of biased PA and SB estimates on, for instance, the development of PA and SB guidelines, it is suggested to re-examine existing accelerometer data and to conduct new large-scale assessments with high resolution and accuracy. Weaknesses of the traditional variable-based approach in the explanation of PA behaviour are illustrated. The application of the alternative person-oriented approach is exemplified using data of the CReActivity project and its potential for intervention design is discussed. Methods for advancement in research designs in order to gain more in-depth insights in the synthesis of PA and SB are presented.

6 References

Ahn, S., & Fedewa, A. L. (2011). A Meta-analysis of the Relationship Between Children's Physical Activity and Mental Health. *Journal of Pediatric Psychology, 36*(4), 385-397. doi:10.1093/jpepsy/jsq107

Andersen, L. B., Riddoch, C., Kriemler, S., & Hills, A. (2011). Physical activity and cardiovascular risk factors in children. *British Journal of Sports Medicine, 45*(11), 871-876. doi:10.1136/bjsports-2011-090333

Bailey, R. C., Olson, J., Pepper, S. L., Porszasz, J., Barstow, T. J., & Cooper, D. M. (1995). The level and tempo of children's physical activities: an observational study. *Medicine & Science in Sports & Exercise, 27*(7), 1033-1041. doi:10.1249/00005768-199507000-00012

Banda, J. A., Haydel, K. F., Davila, T., Desai, M., Bryson, S., Haskell, W. L., . . . Robinson, T. N. (2016). Effects of Varying Epoch Lengths, Wear Time Algorithms, and Activity Cut-Points on Estimates of Child Sedentary Behavior and Physical Activity from Accelerometer Data. *PLoS One, 11*(3), e0150534. doi:10.1371/journal.pone.0150534

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: W H Freeman & Co.

Baranowski, T., Anderson, C., & Carmack, C. (1998). Mediating variable framework in physical activity interventions. How are we doing? How might we do better? *American Journal of Preventive Medicine, 15*(4), 266-297. doi:10.1016/s0749-3797(98)00080-4

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J., & Martin, B. W. (2012). Correlates of physical activity: why are some people physically active and others not? *The Lancet, 380*(9838), 258-271. doi:10.1016/s0140-6736(12)60735-1

Bauman, A. E., Sallis, J. F., Dzewaltowski, D. A., & Owen, N. (2002). Toward a better understanding of the influences on physical activity: The role of determinants, correlates, causal variables, mediators, moderators, and confounders. *American Journal of Preventive Medicine, 23*(2, Supplement 1), 5-14. doi:https://doi.org/10.1016/S0749-3797(02)00469-5

Bechter, B. E., Dimmock, J. A., Howard, J. L., Whipp, P. R., & Jackson, B. (2018). Student motivation in high school physical education: A latent profile analysis approach. *Journal of Sport & Exercise Psychology, 40*(4), 206-216. doi:10.1123/jsep.2018-0028

Bell, A. (2007). Designing and testing questionnaires for children. *Journal of Research in Nursing, 12*(5), 461-469. doi:10.1177/1744987107079616

Bergman, L. R., & Andersson, H. (2010). The person and the variable in developmental psychology. *Zeitschrift für Psychologie/Journal of Psychology, 218*(3), 155-165. doi:10.1027/0044-3409/a000025

Bergman, L. R., & Lundh, L.-G. (2015). Introduction: The Person-Oriented Approach: Roots and Roads to the Future. *Journal for Person-Oriented Research, 1*, 1-6. doi:10.17505/jpor.2015.01

Biddle, S. J. H., Atkin, A. J., Cavill, N., & Foster, C. (2011). Correlates of physical activity in youth: a review of quantitative systematic reviews. *International Review of Sport and Exercise Psychology, 4*(1), 25-49. doi:10.1080/1750984x.2010.548528

Biddle, S. J. H., Ciaccioni, S., Thomas, G., & Vergeer, I. (2019). Physical activity and mental health in children and adolescents: An updated review of reviews and an analysis of causality. *Psychology of Sport and Exercise, 42*, 146-155. doi:https://doi.org/10.1016/j.psychsport.2018.08.011

Biswas, A., Oh, P. I., Faulkner, G. E., Bajaj, R. R., Silver, M. A., Mitchell, M. S., & Alter, D. A. (2015). Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Annals of Internal Medicine, 162*(2), 123-132. doi:10.7326/m14-1651

Borgers, N., de Leeuw, E., & Hox, J. (2000). Children as Respondents in Survey Research: Cognitive Development and Response Quality 1. *Bulletin of Sociological Methodology/Bulletin de Méthodologie Sociologique, 66*(1), 60-75. doi:10.1177/075910630006600106

Borgers, N., Hox, J., & Sikkel, D. (2003). Response Quality in Survey Research with Children and Adolescents: The Effect of Labeled Response Options and Vague Quantifiers. *International Journal of Public Opinion Research, 15*(1), 83-94. doi:10.1093/ijpor/15.1.83

Brand, R., & Ekkekakis, P. (2018). Affective–Reflective Theory of physical inactivity and exercise. *German Journal of Exercise and Sport Research, 48*(1), 48-58. doi:10.1007/s12662-017-0477-9

Brislin, R. W. (1970). Back-Translation for Cross-Cultural Research. *Journal of Cross-Cultural Psychology, 1*(3), 185-216. doi:10.1177/135910457000100301

Brooke, H. L., Corder, K., Atkin, A. J., & van Sluijs, E. M. (2014). A systematic literature review with meta-analyses of within- and between-day differences in objectively measured physical activity in school-aged children. *Sports Medicine, 44*(10), 1427-1438. doi:10.1007/s40279-014-0215-5

Buchan, D. S., Ollis, S., Thomas, N. E., & Baker, J. S. (2012). Physical activity behaviour: an overview of current and emergent theoretical practices. *Journal of Obesity, 2012*, 546459. doi:10.1155/2012/546459

Buchheit, M., Platat, C., Oujaa, M., & Simon, C. (2007). Habitual physical activity, physical fitness and heart rate variability in preadolescents. *International Journal of Sports Medicine, 28*(3), 204-210. doi:10.1055/s-2006-924296

Budayan, C., Dikmen, I., & Birgonul, M. T. (2009). Comparing the performance of traditional cluster analysis, self-organizing maps and fuzzy C-means method for strategic grouping. *Expert Systems with Applications, 36*(9), 11772-11781. doi:https://doi.org/10.1016/j.eswa.2009.04.022

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., . . . Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451-1462. doi:10.1136/bjsports-2020-102955

Burchartz, A., Anedda, B., Auerswald, T., Giurgiu, M., Hill, H., Ketelhut, S., . . . Nigg, C. (2020). Assessing physical behavior through accelerometry–State of the science, best practices and future directions. *Psychology of Sport and Exercise, 49*, 101703.

Burchartz, A., Manz, K., Anedda, B., Niessner, C., Oriwol, D., Schmidt, S. C., & Woll, A. (2020). Measurement of Physical Activity and Sedentary Behavior by Accelerometry Among a Nationwide Sample from the KiGGS and MoMo Study: Study Protocol. *JMIR Research Protocols, 9*(7), e14370. doi:10.2196/14370

Camacho-Minano, M. J., LaVoi, N. M., & Barr-Anderson, D. J. (2011). Interventions to promote physical activity among young and adolescent girls: a systematic review. *Health Education Research, 26*(6), 1025-1049. doi:10.1093/her/cyr040

Carson, V., Hunter, S., Kuzik, N., Gray, C. E., Poitras, V. J., Chaput, J. P., . . . Tremblay, M. S. (2016). Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update. *Applied Physiology, Nutrition, and Metabolism, 41*(6 Suppl 3), 240-265. doi:10.1139/apnm-2015-0630

Cha, E. S., Kim, K. H., & Erlen, J. A. (2007). Translation of scales in cross-cultural research: issues and techniques. *Journal of Advanced Nursing, 58*(4), 386-395. doi:10.1111/j.1365-2648.2007.04242.x

Chatzisarantis, N. L., & Hagger, M. S. (2009). Effects of an intervention based on self-determination theory on self-reported leisure-time physical activity participation. *Psychology & Health, 24*(1), 29-48. doi:10.1080/08870440701809533

Chen, B., Vansteenkiste, M., Beyers, W., Boone, L., Deci, E. L., Van der Kaap-Deeder, J., . . . Verstuyf, J. (2015). Basic psychological need satisfaction, need frustration, and need strength across four cultures. *Motivation and Emotion, 39*(2), 216-236. doi:10.1007/s11031-014-9450-1

Chinapaw, M. J. M., de Niet, M., Verloigne, M., De Bourdeaudhuij, I., Brug, J., & Altenburg, T. M. (2014). From Sedentary Time to Sedentary Patterns: Accelerometer Data

Reduction Decisions in Youth. *PLoS One, 9*(11), e111205. doi:10.1371/journal.pone.0111205

Choi, L., Liu, Z., Matthews, C. E., & Buchowski, M. S. (2011). Validation of accelerometer wear and nonwear time classification algorithm. *Medicine & Science in Sports & Exercise, 43*(2), 357-364. doi:10.1249/MSS.0b013e3181ed61a3

Cooper, A., Goodman, A., Page, A., Sherar, L., Esliger, D., Sluijs, E., . . . Ekelund, U. (2015). Objectively measured physical activity and sedentary time in youth: The International children's accelerometry database (ICAD). *International Journal of Behavioral Nutrition and Physical Activity, 12*, 113. doi:10.1186/s12966-015-0274-5

Corder, K., van Sluijs, E. M., Steele, R. M., Stephen, A. M., Dunn, V., Bamber, D., . . . Ekelund, U. (2011). Breakfast consumption and physical activity in British adolescents. *The British Journal of Nutrition, 105*(2), 316-321. doi:10.1017/s0007114510003272

Craggs, C., Corder, K., van Sluijs, E. M., & Griffin, S. J. (2011). Determinants of change in physical activity in children and adolescents: a systematic review. *American Journal of Preventive Medicine, 40*(6), 645-658. doi:10.1016/j.amepre.2011.02.025

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227-268. doi:10.1207/S15327965PLI1104_01

Dedrick, R., & Greenbaum, P. (2011). Multilevel Confirmatory Factor Analysis of a Scale Measuring Interagency Collaboration of Children's Mental Health Agencies. *Journal of Emotional and Behavioral Disorders, 19*, 27-40. doi:10.1177/1063426610365879

Demetriou, Y., & Bachner, J. (2019). A school-based intervention based on self-determination theory to promote girls' physical activity: study protocol of the CReActivity cluster randomised controlled trial. *BMC Public Health, 19*(1), 519. doi:10.1186/s12889-019-6817-y

Demetriou, Y., Bucksch, J., Hebestreit, A., Schlund, A., Niessner, C., Schmidt, S. C. E., . . . Reimers, A. K. (2019). Germany’s 2018 report card on physical activity for children and youth. *German Journal of Exercise and Sport Research, 49*(2), 113-126. doi:10.1007/s12662-019-00578-1

Diethelm, K., Jankovic, N., Moreno, L. A., Huybrechts, I., De Henauw, S., De Vriendt, T., . . . Kersting, M. (2012). Food intake of European adolescents in the light of different food-based dietary guidelines: results of the HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) Study. *Public Health Nutrition, 15*(3), 386-398. doi:10.1017/S1368980011001935

Dishman, R. K., Hales, D. P., Sallis, J. F., Saunders, R., Dunn, A. L., Bedimo-Rung, A. L., & Ring, K. B. (2010). Validity of social-cognitive measures for physical activity in

middle-school girls. *Journal of Pediatric Psychology, 35*(1), 72-88. doi:10.1093/jpepsy/jsp031

Dollman, J., Okely, A. D., Hardy, L., Timperio, A., Salmon, J., & Hills, A. P. (2009). A hitchhiker's guide to assessing young people's physical activity: Deciding what method to use. *Journal of Science and Medicine in Sport, 12*(5), 518-525. doi:10.1016/j.jsams.2008.09.007

Dumith, S. C., Gigante, D. P., Domingues, M. R., & Kohl, H. W., 3rd. (2011). Physical activity change during adolescence: a systematic review and a pooled analysis. *International Journal of Epidemiology, 40*(3), 685-698. doi:10.1093/ije/dyq272

Dunton, G. F. (2017). Ecological Momentary Assessment in Physical Activity Research. *Exercise and Sport Sciences Reviews, 45*(1), 48-54. doi:10.1249/jes.0000000000000092

Ekelund, U., Steene-Johannessen, J., Brown, W. J., Fagerland, M. W., Owen, N., Powell, K. E., . . . Lee, I. M. (2016). Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *The Lancet, 388*(10051), 1302-1310. doi:10.1016/S0140-6736(16)30370-1

Emm-Collison, L. G., Sebire, S. J., Salway, R., Thompson, J. L., & Jago, R. (2020). Multidimensional motivation for exercise: A latent profile and transition analysis. *Psychology of Sport and Exercise, 47*, 101619. doi:https://doi.org/10.1016/j.psychsport.2019.101619

Emm-Collison, L. G., Standage, M., & Gillison, F. B. (2016). Development and Validation of the Adolescent Psychological Need Support in Exercise Questionnaire. *Journal of Sport & Exercise Psychology, 38*(5), 505-520. doi:10.1123/jsep.2015-0220

Esteban-Cornejo, I., Tejero-González, C. M., Martinez-Gomez, D., Cabanas-Sánchez, V., Fernández-Santos, J. R., Conde-Caveda, J., . . . Group, D. S. (2014). Objectively measured physical activity has a negative but weak association with academic performance in children and adolescents. *Acta Paediatrica, 103*(11), e501-e506. doi:https://doi.org/10.1111/apa.12757

Estevan, I., García-Massó, X., Molina-García, J., & Barnett, L. M. (2019). Identifying profiles of children at risk of being less physically active: an exploratory study using a self-organised map approach for motor competence. *Journal of Sports Sciences, 37*(12), 1356-1364. doi:10.1080/02640414.2018.1559491

Evans, J. S. B. T., & Stanovich, K. E. (2013). Dual-Process Theories of Higher Cognition: Advancing the Debate. *Perspectives on Psychological Science, 8*(3), 223-241. doi:10.1177/1745691612460685

Feltz, D. L., Short, S. E., & Sullivan, P. J. (2008). *Self-efficacy in sport*. Champaign, IL, US: Human Kinetics.

Finger, J. D., Varnaccia, G., Borrmann, A., Lange, C., & Mensink, G. (2018). Körperliche Aktivität von Kindern und Jugendlichen in Deutschland – Querschnittergebnisse aus KiGGS Welle 2 und Trends. *Journal of Health Monitoring, 3*(1), 24-31. doi:http://dx.doi.org/10.25646/2957.2

Goetz, L. H., & Schork, N. J. (2018). Personalized medicine: motivation, challenges, and progress. *Fertility and Sterility, 109*(6), 952-963. doi:10.1016/j.fertnstert.2018.05.006

Granger, E., Di Nardo, F., Harrison, A., Patterson, L., Holmes, R., & Verma, A. (2017). A systematic review of the relationship of physical activity and health status in adolescents. *European Journal of Public Health, 27*(suppl_2), 100-106. doi:10.1093/eurpub/ckw187

Gut, V., Schmid, J., & Conzelmann, A. (2020). The interaction of behavioral context and motivational-volitional factors for exercise and sport in adolescence: patterns matter. *BMC Public Health, 20*(1), 570. doi:10.1186/s12889-020-08617-5

Guthold, R., Cowan, M. J., Autenrieth, C. S., Kann, L., & Riley, L. M. (2010). Physical activity and sedentary behavior among schoolchildren: a 34-country comparison. *Journal of Pediatrics, 157*(1), 43-49.e41. doi:10.1016/j.jpeds.2010.01.019

Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2020). Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1.6 million participants. *The Lancet Child & Adolescent Health, 4*(1), 23-35. doi:10.1016/S2352-4642(19)30323-2

Hagger, M. (2010). Current issues and new directions in Psychology and Health: Physical activity research showcasing theory into practice. *Psychology & Health, 25*(1), 1-5. doi:10.1080/08870440903268637

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., & Ekelund, U. (2012). Global physical activity levels: surveillance progress, pitfalls, and prospects. *The Lancet, 380*(9838), 247-257. doi:https://doi.org/10.1016/S0140-6736(12)60646-1

Hallal, P. C., Wells, J. C., Reichert, F. F., Anselmi, L., & Victora, C. G. (2006). Early determinants of physical activity in adolescence: prospective birth cohort study. *BMJ, 332*(7548), 1002-1007. doi:10.1136/bmj.38776.434560.7C

Hänggi, J. M., Phillips, L. R., & Rowlands, A. V. (2013). Validation of the GT3X ActiGraph in children and comparison with the GT1M ActiGraph. *Journal of Science and Medicine in Sport, 16*(1), 40-44. doi:10.1016/j.jsams.2012.05.012

Hardin, A. P., Hackell, J. M., & Simon, G. R. (2017). Age limit of pediatrics. *Pediatrics, 140*(3), e20172151.

Herrero-Herrero, M., García-Massó, X., Martínez-Corralo, C., Prades-Piñón, J., & Sanchis-Alfonso, V. (2017). Relationship between the practice of physical activity and quality of movement in adolescents: a screening tool using self-organizing maps. *The Physician and Sportsmedicine, 45*(3), 271-279. doi:10.1080/00913847 .2017.1327303

Hu, L. t., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1-55. doi:10.1080/10705519909540118

Huang, F. (2017). Conducting Multilevel Confirmatory Factor Analysis Using R. *Working paper*.

Huang, F., Cornell, D. G., Konold, T., Meyer, J. P., Lacey, A., Nekvasil, E. K., . . . Shukla, K. D. (2015). Multilevel Factor Structure and Concurrent Validity of the Teacher Version of the Authoritative School Climate Survey. *Journal of School Health, 85*(12), 843-851. doi:10.1111/josh.12340

IBM Corp. (2017). IBM SPSS Statistics for Windows (Version 25). Armonk, NY: IBM Corp.

Jago, R., Salway, R., Emm-Collison, L., Sebire, S. J., Thompson, J. L., & Lawlor, D. A. (2020). Association of BMI category with change in children's physical activity between ages 6 and 11 years: a longitudinal study. *International Journal of Obesity, 44*(1), 104-113. doi:10.1038/s41366-019-0459-0

Jiménez-Pavón, D., Kelly, J., & Reilly, J. J. (2010). Associations between objectively measured habitual physical activity and adiposity in children and adolescents: Systematic review. *International Journal of Pediatric Obesity, 5*(1), 3-18. doi:10.3109/17477160903067601

Julian, M. W. (2001). The Consequences of Ignoring Multilevel Data Structures in Nonhierarchical Covariance Modeling. *Structural Equation Modeling: A Multidisciplinary Journal, 8*(3), 325-352. doi:10.1207/S15328007SEM0803_1

Keadle, S. K., Shiroma, E. J., Freedson, P. S., & Lee, I. M. (2014). Impact of accelerometer data processing decisions on the sample size, wear time and physical activity level of a large cohort study. *BMC Public Health, 14*, 1210. doi:10.1186/1471-2458-14-1210

Kelso, A., Linder, S., Reimers, A. K., Klug, S. J., Alesi, M., Scifo, L., . . . Demetriou, Y. (2020). Effects of school-based interventions on motivation towards physical activity in children and adolescents: A systematic review and meta-analysis. *Psychology of Sport and Exercise, 51*, 101770. doi:https://doi.org/10.1016/j.psychsport. 2020.101770

Kim, Y., Beets, M. W., & Welk, G. J. (2012). Everything you wanted to know about selecting the "right" Actigraph accelerometer cut-points for youth, but…: a systematic review.

Journal of Science and Medicine in Sport, 15(4), 311-321. doi:10.1016/j.jsams.2011.12.001

Kohonen, T. (1995). *The self-organizing map*. Heidelberg: Springer-Verlag.

Kohonen, T., Nieminen, I. T., & Honkela, T. (2009). *On the Quantization Error in SOM vs. VQ: A Critical and Systematic Study*.

Konstabel, K., Veidebaum, T., Verbestel, V., Moreno, L. A., Bammann, K., Tornaritis, M., . . . Pitsiladis, Y. (2014). Objectively measured physical activity in European children: the IDEFICS study. *International Journal of Obesity, 38 Suppl 2*, 135-143. doi:10.1038/ijo.2014.144

Korner-Nievergelt, F., Roth, T., von Felten, S., Guélat, J., Almasi, B., & Korner-Nievergelt, P. (2015). Model Selection and Multimodel Inference. In *Bayesian Data Analysis in Ecology Using Linear Models with R, BUGS, and STAN* (pp. 175-196). Amsterdam: Academic Press.

Kriemler, S., Manser-Wenger, S., Zahner, L., Braun-Fahrländer, C., Schindler, C., & Puder, J. J. (2008). Reduced cardiorespiratory fitness, low physical activity and an urban environment are independently associated with increased cardiovascular risk in children. *Diabetologia, 51*(8), 1408-1415. doi:10.1007/s00125-008-1067-z

Lindwall, M., Ivarsson, A., Weman-Josefsson, K., Jonsson, L., Ntoumanis, N., Patrick, H., . . . Teixeira, P. (2017). Stirring the motivational soup: within-person latent profiles of motivation in exercise. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 4. doi:10.1186/s12966-017-0464-4

Loprinzi, P. D., & Cardinal, B. J. (2011). Measuring Children's Physical Activity and Sedentary Behaviors. *Journal of Exercise Science & Fitness, 9*(1), 15-23. doi:https://doi.org/10.1016/S1728-869X(11)60002-6

Markland, D., & Tobin, V. (2004). A Modification to the Behavioural Regulation in Exercise Questionnaire to Include an Assessment of Amotivation. *Journal of Sport and Exercise Psychology, 26*(2), 191-196. doi:10.1123/jsep.26.2.191

Mattocks, C., Tilling, K., Ness, A., & Riddoch, C. (2008). Improvements in the Measurement of Physical Activity in Childhood Obesity Research; Lessons from Large Studies of Accelerometers. *Clinical Medicine Insights: Pediatrics, 2*, 27-36. doi:10.4137/CMPed.S1127

McKinney, J., Lithwick, D. J., Morrison, B., Nazzari, H., Isserow, S. H., Heilbron, B., & Krahn, A. D. (2016). The health benefits of physical activity and cardiorespiratory fitness. *British Columbia Medical Journal, 58*(3), 131-137.

Melo Riveros, N. A., Cardenas Espitia, B. A., & Aparicio Pico, L. E. (2019). Comparison between K-means and Self-Organizing Maps algorithms used for diagnosis spinal

column patients. *Informatics in Medicine Unlocked, 16*, 100206. doi:https://doi.org/10.1016/j.imu.2019.100206

Migueles, J. H., Cadenas-Sanchez, C., Ekelund, U., Delisle Nystrom, C., Mora-Gonzalez, J., Lof, M., . . . Ortega, F. B. (2017). Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations. *Sports Medicine, 47*(9), 1821-1845. doi:10.1007/s40279-017-0716-0

Migueles, J. H., Cadenas-Sanchez, C., Tudor-Locke, C., Löf, M., Esteban-Cornejo, I., Molina-Garcia, P., . . . Ortega, F. B. (2019). Comparability of published cut-points for the assessment of physical activity: Implications for data harmonization. *Scandinavian Journal of Medicine & Science in Sports, 29*(4), 566-574. doi:10.1111/sms.13356

Molina-García, J., Queralt, A., Adams, M. A., Conway, T. L., & Sallis, J. F. (2017). Neighborhood built environment and socio-economic status in relation to multiple health outcomes in adolescents. *Preventive Medicine, 105*, 88-94. doi:10.1016/j.ypmed.2017.08.026

Morin, A. J. S., & Marsh, H. W. (2015). Disentangling Shape from Level Effects in Person-Centered Analyses: An Illustration Based on University Teachers' Multidimensional Profiles of Effectiveness. *Structural Equation Modeling: A Multidisciplinary Journal, 22*(1), 39-59. doi:10.1080/10705511.2014.919825

Nahum-Shani, I., Hekler, E. B., & Spruijt-Metz, D. (2015). Building health behavior models to guide the development of just-in-time adaptive interventions: A pragmatic framework. *Health psychology, 34s*(0), 1209-1219. doi:10.1037/hea0000306

Nigg, C. R., Fuchs, R., Gerber, M., Jekauc, D., Koch, T., Krell-Roesch, J., . . . Woll, A. (2020). Assessing physical activity through questionnaires – A consensus of best practices and future directions. *Psychology of Sport and Exercise, 50*, 101715. doi:https://doi.org/10.1016/j.psychsport.2020.101715

Nold, D. (2010). Sozioökonomischer Status von Schülerinnen und Schülern 2008. Ergebnisse des Mikrozensus. *Wirtschaft und Statistik*(2), 138-149.

Olds, T. S., Tomkinson, G. R., Ferrar, K. E., & Maher, C. A. (2010). Trends in the prevalence of childhood overweight and obesity in Australia between 1985 and 2008. *International Journal of Obesity, 34*(1), 57-66. doi:10.1038/ijo.2009.211

Oliver Gasch, E., Vallés Pérez, I., Baños Rivera, R. M., Cebolla i Martí, A. J., Botella Arbona, C., & Soria Olivas, E. (2018). Visual data mining with self-organizing maps for "self-monitoring" data analysis. *Sociological Methods & Research, 47*(3), 492-506. doi:https://doi.org/10.1177/0049124116661576

Owen, K. B., Smith, J., Lubans, D. R., Ng, J. Y. Y., & Lonsdale, C. (2014). Self-determined motivation and physical activity in children and adolescents: A systematic review and meta-analysis. *Preventive Medicine, 67*, 270-279. doi:https://doi.org/10.1016/j.ypmed.2014.07.033

Pellicer-Chenoll, M., García-Massó, X., Morales, J., Serra-Ano, P., Solana-Tramunt, M., Gonzalez, L. M., & Toca-Herrera, J. L. (2015). Physical activity, physical fitness and academic achievement in adolescents: a self-organizing maps approach. *Health Education Research, 30*(3), 436-448. doi:10.1093/her/cyv016

Pfitzner, R., Gorzelniak, L., Heinrich, J., von Berg, A., Klümper, C., Bauer, C. P., . . . Schulz, H. (2013). Physical activity in German adolescents measured by accelerometry and activity diary: introducing a comprehensive approach for data management and preliminary results. *PLoS One, 8*(6), e65192. doi:10.1371/journal.pone.0065192

Pickering, T. A., Huh, J., Intille, S., Liao, Y., Pentz, M. A., & Dunton, G. F. (2016). Physical Activity and Variation in Momentary Behavioral Cognitions: An Ecological Momentary Assessment Study. *Journal of Physical Activity and Health, 13*(3), 344-351. doi:10.1123/jpah.2014-0547

Rachele, J. N., McPhail, S. M., Washington, T. L., & Cuddihy, T. F. (2012). Practical physical activity measurement in youth: a review of contemporary approaches. *World Journal of Pediatrics, 8*(3), 207-216. doi:10.1007/s12519-012-0359-z

Reis, V. M., den Tillaar, R. V., & Marques, M. C. (2011). Higher Precision of Heart Rate Compared with VO2 to Predict Exercise Intensity in Endurance-Trained Runners. *Journal of Sports Science and Medicine, 10*(1), 164-168.

Revelle, W. R. (2017). psych: Procedures for personality and psychological research.

Rhodes, R. E., & Dickau, L. (2012). Experimental evidence for the intention-behavior relationship in the physical activity domain: a meta-analysis. *Health psychology, 31*(6), 724-727. doi:10.1037/a0027290

Rhodes, R. E., Janssen, I., Bredin, S. S. D., Warburton, D. E. R., & Bauman, A. E. (2017). Physical activity: Health impact, prevalence, correlates and interventions. *Psychology & Health, 32*(8), 942-975. doi:10.1080/08870446.2017.1325486

Rhodes, R. E., McEwan, D., & Rebar, A. L. (2019). Theories of physical activity behaviour change: A history and synthesis of approaches. *Psychology of Sport and Exercise, 42*, 100-109. doi:https://doi.org/10.1016/j.psychsport.2018.11.010

Rhodes, R. E., & Nigg, C. R. (2011). Advancing physical activity theory: a review and future directions. *Exercise and Sport Sciences Reviews, 39*(3), 113-119. doi:10.1097/JES.0b013e31821b94c8

Rhodes, R. E., Saelens, B. E., & Sauvage-Mar, C. (2018). Understanding Physical Activity through Interactions Between the Built Environment and Social Cognition: A

Systematic Review. *Sports Medicine, 48*(8), 1893-1912. doi:10.1007/s40279-018-0934-0

Rosseel, Y. (2012). lavaan: An R Package for Structural Equation Modeling and more. Version 0.5–12 (BETA). *Journal of Statistical Software, 48*(2), 1-36.

Ruiz, J. R., Ortega, F. B., Martínez-Gómez, D., Labayen, I., Moreno, L. A., De Bourdeaudhuij, I., . . . Sjöström, M. (2011). Objectively measured physical activity and sedentary time in European adolescents: the HELENA study. *American Journal of Epidemiology, 174*(2), 173-184. doi:10.1093/aje/kwr068

Rütten, A., & Pfeifer, K. (2017). *Nationale Empfehlungen für Bewegung und Bewegungsförderung*. Cologne, Germany: Bundeszentrale für gesundheitliche Aufklärung.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *The American Psychologist, 55*(1), 68-78. doi:https://doi.org/10.1037/0003-066X.55.1.68

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. New York, NY, US: The Guilford Press.

Sallis, J. F., & Owen, N. (1999). *Physical Activity and Behavioral Medicine*: SAGE Publications.

Sallis, J. F., & Owen, N. (2015). Ecological models of health behavior. In *Health behavior: Theory, research, and practice, 5th ed.* (pp. 43-64). Hoboken, NJ, US: Jossey-Bass/Wiley.

Sallis, J. F., Prochaska, J. J., & Taylor, W. C. (2000). A review of correlates of physical activity of children and adolescents. *Medicine & Science in Sports & Exercise, 32*(5), 963-975. doi:10.1097/00005768-200005000-00014

Sawyer, S. M., Azzopardi, P. S., Wickremarathne, D., & Patton, G. C. (2018). The age of adolescence. *The Lancet Child & Adolescent Health, 2*(3), 223-228. doi:10.1016/S2352-4642(18)30022-1

Schwarz, N., & Sudman, S. (1996). *Answering Questions: Methodology for Determining Cognitive and Communicative Processes in Survey Research*. San Francisco: Jossey-Bass.

Scott, J. (1997). Children as Respondents: Methods for Improving Data Quality. In L. Lyberg, P. Biemer, M. Collins, E. De Leeuw, C. Dippo, N. Schwarz, & D. Trewin (Eds.), *Survey Measurement and Process Quality* (pp. 331-350). New York: John Wiley & Sons, Inc.

Sherar, L. B., Griew, P., Esliger, D. W., Cooper, A. R., Ekelund, U., Judge, K., & Riddoch, C. (2011). International children's accelerometry database (ICAD): Design and methods. *BMC Public Health, 11*(1), 485. doi:10.1186/1471-2458-11-485

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological momentary assessment. *Annual Review of Clinical Psychology, 4*, 1-32. doi:10.1146/annurev.clinpsy.3.022806.091415

Sirard, J. R., & Pate, R. R. (2001). Physical activity assessment in children and adolescents. *Sports Medicine, 31*(6), 439-454. doi:10.2165/00007256-200131060-00004

Skinner, A. C., & Skelton, J. A. (2014). Prevalence and Trends in Obesity and Severe Obesity Among Children in the United States, 1999-2012. *JAMA Pediatrics, 168*(6), 561-566. doi:10.1001/jamapediatrics.2014.21

Slootmaker, S. M., Schuit, A. J., Chinapaw, M. J., Seidell, J. C., & van Mechelen, W. (2009). Disagreement in physical activity assessed by accelerometer and self-report in subgroups of age, gender, education and weight status. *International Journal of Behavioral Nutrition and Physical Activity, 6*, 17. doi:10.1186/1479-5868-6-17

Standage, M., Gillison, F. B., Ntoumanis, N., & Treasure, D. C. (2012). Predicting Students' Physical Activity and Health-Related Well-Being: A Prospective Cross-Domain Investigation of Motivation across School Physical Education and Exercise Settings. *Journal of Sport and Exercise Psychology, 34*(1), 37-60. doi:10.1123/jsep.34.1.37

Sterdt, E., Liersch, S., & Walter, U. (2014). Correlates of physical activity of children and adolescents: A systematic review of reviews. *Health Education Journal, 73*(1), 72-89. doi:10.1177/0017896912469578

Sylvester, B. D., Standage, M., McEwan, D., Wolf, S. A., Lubans, D. R., Eather, N., . . . Beauchamp, M. R. (2016). Variety support and exercise adherence behavior: experimental and mediating effects. *Journal of Behavioral Medicine, 39*(2), 214-224. doi:10.1007/s10865-015-9688-4

Teixeira, P. J., Carraça, E. V., Markland, D., Silva, M. N., & Ryan, R. M. (2012). Exercise, physical activity, and self-determination theory: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity, 9*(1), 78. doi:10.1186/1479-5868-9-78

Telama, R. (2009). Tracking of physical activity from childhood to adulthood: a review. *Obesity Facts, 2*(3), 187-195. doi:10.1159/000222244

Thompson, P. D., Crouse, S. F., Goodpaster, B., Kelley, D., Moyna, N., & Pescatello, L. (2001). The acute versus the chronic response to exercise. *Medicine & Science in Sports & Exercise, 33*(6 Suppl), pp. 438-445; discussion pp. 452-433. doi:10.1097/00005768-200106001-00012

Tremblay, M. S., Aubert, S., Barnes, J. D., Saunders, T. J., Carson, V., Latimer-Cheung, A. E., . . . on behalf of, S. T. C. P. P. (2017). Sedentary Behavior Research Network (SBRN) – Terminology Consensus Project process and outcome. *International*

Journal of Behavioral Nutrition and Physical Activity, 14(1), 75. doi:10.1186/s12966-017-0525-8

Troiano, R. P., Stamatakis, E., & Bull, F. C. (2020). How can global physical activity surveillance adapt to evolving physical activity guidelines? Needs, challenges and future directions. *British Journal of Sports Medicine, 54*(24), 1468-1473. doi:10.1136/bjsports-2020-102621

Trost, S. G. (2007). State of the Art Reviews: Measurement of Physical Activity in Children and Adolescents. *American Journal of Lifestyle Medicine, 1*(4), 299-314. doi:10.1177/1559827607301686

Trost, S. G., Marshall, A. L., Miller, R., Hurley, J. T., & Hunt, J. A. (2007). Validation of a 24-h physical activity recall in indigenous and non-indigenous Australian adolescents. *Journal of Science and Medicine in Sport, 10*(6), 428-435. doi:https://doi.org/10.1016/j.jsams.2006.07.018

Uijtdewilligen, L., Nauta, J., Singh, A. S., van Mechelen, W., Twisk, J. W. R., van der Horst, K., & Chinapaw, M. J. M. (2011). Determinants of physical activity and sedentary behaviour in young people: a review and quality synthesis of prospective studies. *British Journal of Sports Medicine, 45*(11), 896-905. doi:10.1136/bjsports-2011-090197

van der Ploeg, H. P., & Hillsdon, M. (2017). Is sedentary behaviour just physical inactivity by another name? *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 142. doi:10.1186/s12966-017-0601-0

Van Hecke, L., Loyen, A., Verloigne, M., van der Ploeg, H. P., Lakerveld, J., Brug, J., . . . consortium, o. b. o. t. D. (2016). Variation in population levels of physical activity in European children and adolescents according to cross-European studies: a systematic literature review within DEDIPAC. *International Journal of Behavioral Nutrition and Physical Activity, 13*(1), 70. doi:10.1186/s12966-016-0396-4

Vanhelst, J., Béghin, L., Salleron, J., Ruiz, J. R., Ortega, F. B., Ottevaere, C., . . . Gottrand, F. (2014). Impact of the choice of threshold on physical activity patterns in free living conditions among adolescents measured using a uniaxial accelerometer: The HELENA study. *Journal of Sports Sciences, 32*(2), 110-115. doi:10.1080/02640414.2013.809473

Vatcheva, K. P., Lee, M., McCormick, J. B., & Rahbar, M. H. (2016). Multicollinearity in Regression Analyses Conducted in Epidemiologic Studies. *Epidemiology (Sunnyvale, Calif.), 6*(2), 227. doi:10.4172/2161-1165.1000227

Vesanto, J., Himberg, J., Alhoniemi, E., & Parhankangas, J. (1999). *Self-organizing map in Matlab: the SOM Toolbox.* Paper presented at the Proceedings of the Matlab DSP conference.

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal, 174*(6), 801-809. doi:10.1503/cmaj.051351

Williams, S. L., & French, D. P. (2011). What are the most effective intervention techniques for changing physical activity self-efficacy and physical activity behaviour - and are they the same? *Health Education Research, 26*(2), 308-322. doi:10.1093/her/cyr005

Woll, A., Oriwol, D., Anedda, B., Burchartz, A., Hanssen-Doose, A., Kopp, M., . . . Worth, A. (2019). *Körperliche Aktivität, motorische Leistungsfähigkeit und Gesundheit in Deutschland: Ergebnisse aus der Motorik-Modul-Längsschnittstudie (MoMo)*.

Yli-Piipari, S., John Wang, C. K., Jaakkola, T., & Liukkonen, J. (2012). Examining the Growth Trajectories of Physical Education Students' Motivation, Enjoyment, and Physical Activity: A Person-Oriented Approach. *Journal of Applied Sport Psychology, 24*(4), 401-417. doi:10.1080/10413200.2012.677096

7 List of Publications

Bachner, J., Sturm, D. J., & Demetriou, Y. (2020). Accelerometer-Measured Physical Activity and Sedentary Behavior Levels and Patterns in Female Sixth Graders: The CReActivity Project. *International Journal of Environmental Research and Public Health, 18*(1), 32. doi:10.3390/ijerph18010032

Bachner, J., Sturm, D. J., García-Massó, X., Molina-García, J., & Demetriou, Y. (2020). Physical Activity-Related Profiles of Female Sixth-Graders Regarding Motivational Psychosocial Variables: A Cluster Analysis Within the CReActivity Project. *Frontiers in Psychology, 11*, 580563. doi:10.3389/fpsyg.2020.580563

Bachner, J., Sturm, D. J., Haug, S., & Demetriou, Y. (2020). Multi-level validation of the German physical activity self-efficacy scale in a sample of female sixth-graders. *BMC Public Health, 20*(1), 979. doi:10.1186/s12889-020-09096-4

Sturm, D. J., Bachner, J., Haug, S., & Demetriou, Y. (2020). The German Basic Psychological Needs Satisfaction in Physical Education Scale: Adaption and Multilevel Validation in a Sample of Sixth-Grade Girls. *International Journal of Environmental Research and Public Health, 17*(5), 1554. doi:10.3390/ijerph17051554

Zimmermann, J., Tilga, H., Bachner, J., & Demetriou, Y. (2020). The German Multi-Dimensional Perceived Autonomy Support Scale for Physical Education: Adaption and Validation in a Sample of Lower Track Secondary School Students. *International Journal of Environmental Research and Public Health, 17*(19), 7353. doi:https://doi.org/10.3390/ijerph17197353

Demetriou, Y., & Bachner, J. (2019). A school-based intervention based on self-determination theory to promote girls' physical activity: study protocol of the CReActivity cluster randomised controlled trial. *BMC Public Health, 19*(1), 519. doi:10.1186/s12889-019-6817-y

Demetriou, Y., Bachner, J., Reimers, A., & Göhner, W. (2018). Effects of a Sports-Oriented Primary School on Students' Physical Literacy and Cognitive Performance. *Journal of Functional Morphology and Kinesiology, 3*(3), 37. doi:https://doi.org/10.3390/jfmk3030037

8 Reprint permissions