Physical Activity in Children and Adults
–
Associations with Affect and Impact on Executive Functions

Dissertation

der Mathematisch-Naturwissenschaftlichen Fakultät

der Eberhard Karls Universität Tübingen

zur Erlangung des Grades eines

Doktors der Naturwissenschaften

(Dr. rer. nat.)

vorgelegt von

Dipl. Psych. Petra Haas, geb. Bugl

aus Heltau, Rumänien

Tübingen

2017

Gedruckt mit Genehmigung der Mathematisch-Naturwissenschaftlichen Fakultät der Eberhard Karls Universität Tübingen.

Tag der mündlichen Qualifikation:	23.02.2017
Dekan:	Prof. Dr. Wolfgang Rosenstiel
1. Berichterstatter:	Prof. Dr. Caterina Gawrilow
2. Berichterstatter:	Prof. Dr. Augustin Kelava

Danksagung

Ganz herzlich möchte ich mich bei allen bedanken, die zum Gelingen dieser Dissertation beigetragen haben.

Ich bedanke mich besonders bei *Prof. Dr. Caterina Gawrilow* für die ausgezeichnete wissenschaftliche Betreuung und die begeisternde Unterstützung während der letzten Jahre. Ebenso danke ich insbesondere *Prof. Dr. Augustin Kelava* für seine methodische Expertise und Flexibilität in der Betreuung dieser Arbeit.

Außerdem gilt mein Dank der *Graduiertenschule & Forschungsnetzwerk LEAD* der Universität Tübingen, die diese Dissertation nicht nur finanziell ermöglicht, sondern auch ideell bereichert hat, sowie allen diskussionsfreudigen und inspirierenden *LEAD-Mitgliedern*.

Mein Dank geht ebenfalls an *Dr. Turu Stadler* für ihren herausragenden Enthusiasmus und ihre stetige Begleitung bei inhaltsbezogenen und methodischen Diskussionspunkten. Ebenso danke ich *Prof. Dr. Gorden Sudeck* für seine großzügige Unterstützung bei allen sportwissenschaftlichen Aspekten dieser Arbeit und der Rekrutierung von Kindergärten.

Ganz besonders möchte ich mich auch bei *Dr. Christiane Fiege, Parvin Nemati, Friederike Blume* und *Dr. Jan Kühnhausen* vom Arbeitsbereich Schulpsychologie bedanken, die meine Arbeit auf vielfältige Art und Weise begleitet haben, ebenso bei *Dr. Johanna Schmid* für die zuverlässige konstruktive Unterstützung, und insbesondere auch bei *Merle Reuter* und *Leona Hellwig* für den motivierenden Austausch über Höhen und Tiefen des wissenschaftlichen Lebens und die einzigartige gemeinsame Zeit.

Allen Kindern, Eltern und jungen Erwachsenen danke ich für die Teilnahme an den beiden Studien dieser Arbeit und ebenso danke ich den überaus engagierten Bachelor-, Master- und DiplomarbeitskandidatInnen, *Therese Andrä, Petra Barth, Marcel Cattarius, Ophelia Koller, Marie Meibohm, Kristina Mihaylova* und *Sarah Schmid*, für die gelungene Zusammenarbeit.

Mein herzlicher Dank gilt auch meinen Eltern *Doris und Peter Bugl*, meinem Bruder, sowie all meinen Freundinnen und Freunden, die immer hinter mir standen, und nicht zuletzt meinem Mann *Stephan* für seine vorbildhafte Leichtigkeit bei jeglichem Bemühen.

Contents

List of Tables

List of Figures

List of Abbreviations

ICD-10	International Classification of Diseases, 10th edition
MET	Metabolic equivalent of task
POMS	Profile of Mood States
POMS-15	Profile of Mood States, 15-item version
VO^2max	Maximal oxygen uptake, aerobic capacity
WHO	World Health Organization

List of Manuscripts

This dissertation is based on the following three manuscripts:

I. Haas, P., Schmid, J., Stadler, G., Reuter, M., & Gawrilow, C. (in press). Zooming into daily life: Within-person associations between physical activity and affect in young adults. *Psychology & Health.*

II. Bugl, P., Schmid, J. & Gawrilow, C. (2015). Ambulantes Assessment in der Schule: Den schulischen Alltag erfahrbar machen [Ambulatory assessment in school: Discovering daily school life]. *Lernen und Lernstörungen, 4*, 261–268. doi:10.1024/2235-0977/a000115

III. Haas, P., Cattarius, M., Meibohm, M., Schmid, J., Sudeck, G., Kelava, A., & Gawrilow, C. (2017). Improving young children's executive functions with physical activity: The role of motor coordination experiences. *Manuscript in preparation.*

ABSTRACT

Physical inactivity is a wide-spread phenomenon in the Western world. It has detrimental influences on health, resulting in the fourth-leading risk factor of global mortality. In addition to being an effective tool for improving physical health, physical activity can also serve to improve mental health. The present dissertation aims at investigating the potential benefits of physical activity for affect and executive functions, both representing aspects of mental health. To be more precise, the research aim of the present dissertation is trifold. First, the associations between physical activity and affect in young adults' daily lives are investigated by applying ambulatory assessment (*Manuscript 1*). Second, the application of ambulatory assessment in the school context, including the assessment of physical activity, affect and executive functions, and its advantages for supporting educational success are reviewed (*Manuscript 2*). Third, the effectiveness of a physical activity intervention for improving executive functions in young children is investigated in a standardized intervention study (*Manuscript 3*). Thereby, the present dissertation extends and enriches theoretical and empirical knowledge in two ways. On the one hand, it focuses in particular on the transfer of effects into everyday life by relying on ambulatory assessment. On the other hand, it targets specific age groups, young adults and young children, that seem to be highly susceptible for the benefits of physical activity since young adults' affect is especially low and young children's executive functions are still developing.

Manuscript 1 investigated the associations between physical activity and affect in young adults' daily lives. Ambulatory assessment was applied in an intensive longitudinal study, conducted in 189 young adults across 10 consecutive days. Participants wore accelerometers to objectively assess moderate-to-vigorous physical activity continuously throughout the day and reported their affect in time-stamped online diaries before going to sleep. Multilevel analyses revealed significant within-person associations between daytime physical activity and same-day's evening affect. On days when participants engaged in more activity than usual, they reported not only less depressed and less angry affect in the evening, but also more vigor and serenity. These results extend previous findings with evidence obtained in real life and by focusing on the associations between physical activity and specific affect states. Further

on, the results of this manuscript allow deriving practical implications for health promotion programs for young adults.

Manuscript 2 provided a literature review on the application of ambulatory assessment in the school context. It introduced ambulatory assessment as a method that enables investigating fluctuations in physiological and mental processes within students and teachers. Specifically, applying ambulatory assessment methods can detect intraindividual changes and fluctuations in behavioral (e.g., physical activity), affective, and cognitive (e.g. executive functions) processes as they naturally occur within a school day or across days. Thereby, a high ecological validity can be reached and contextual factors of various modalities are assessable. Moreover, the results of ambulatory assessment studies in school can lay the foundation for developing theories on the etiology of academic achievement. Consequently, this manuscript highlights the benefits of applying ambulatory assessment in school to support educational success.

Manuscript 3 described a standardized intervention study in 103 young children that tests the effectiveness of acute physical activity for improving executive functions and also takes the moderating influence of previous motor coordination experiences into account. Children were randomly assigned to a physical activity or sitting control condition, both conducted in a one-on-one experimenter-child setting. Executive functions were assessed with two tasks directly following the interventions. Motor coordination experiences were measured with a parental questionnaire. Regression analyses revealed no difference in both executive function tasks between children in the physical activity compared to the control condition. However, individual differences in children's motor coordination experiences moderated the effectiveness of physical activity for executive functions. Children with lower levels of motor coordination experiences showed negative effects of physical activity on executive functions compared to a sitting activity, whereas children with higher levels of motor coordination experiences showed a trend indicating positive effects of physical activity on executive functions. These results allow drawing causal inferences about the effects of physical activity on executive functions and extend prior findings by its application of standardized methods in young children. Furthermore, practical implications for the use of physical activity in early education can be derived.

As a whole, the present dissertation shows that physical activity can serve as a tool for enhancing affect in young adults and executive functions in young children, and thus, for improving mental health. In addition, it underlines the value of applying

ambulatory assessment to obtain evidence in real life and in particular in the school context to support education. Consequently, the present dissertation contributes conceptual knowledge about the potential of physical activity for improving affect and executive functions. Practical implications for how physical activity can be used to support health and education are discussed together with directions for future research.

1 INTRODUCTION

The way we spend our time has greatly changed in the Western world during the last decades. The increasing mechanization and technization have not only led to notable improvements in everyday life, but also raised new challenges, as for instance to maintain a physically active lifestyle (Vaynman & Gomez-Pinilla, 2006). Today, 95% of adults and 58% of children show less daily physical activity (Troiano et al., 2008) than advised by national and international recommendations for health prevention (American Heart Association, 2016; European Working Group, 2008). In fact, physical inactivity constitutes the fourth leading risk factor for global mortality nowadays (World Health Organization [WHO], 2014). Engaging in physical activity, however, bears multiple advantages not only for physical health, but also for mental health. Prior evidence demonstrates that physical activity can go along with improved *mental health* (Deslandes et al., 2009; for a definition of mental health, see Galderisi, Heinz, Kastrup, Beezhold, & Sartorius, 2015), ranging from enhanced *well-being*, such as affect (Conn, 2010) to enhanced *cognitive functioning*, such as executive functions (Colcombe & Kramer, 2003). When considering the importance of mental health on the individual level, it becomes apparent that it is a precondition for high levels of social and academic functioning. Individuals with high well-being do not only feel better, but can also better cope with their environment and also show better physical health (Diener & Chan, 2011). High cognitive functioning can support individuals to be successful in their academic lives (e.g., Preßler, Könen, Hasselhorn, & Krajewski, 2014) and thereby strengthens educational and occupational success. Applying a more general perspective, societies benefit from fostering mental health of their citizens as this goes along with decreased health care costs as well as with more equitable social interactions (WHO, 2013). Consequently, research on the potential of physical activity for improving (a) well-being, such as affect, and (b) cognitive functioning, such as executive functions, is needed. A more detailed knowledge of how to use physical activity to achieve benefits for well-being and cognitive functioning can inspire health promotion programs and support education.

The potential of physical activity to improve (a) *affect* as one aspect of well-being is oftentimes considered common knowledge. Affect refers to transient and subjective episodes of feelings easily changeable by context (Cranford et al., 2006). Most individuals are convinced that they feel better after having engaged in physical

activity. In line with this hypothesis, previous evidence suggests that physical activity interventions improve affect (Mammen & Faulkner, 2013). However, two important aspects are worth to be considered and are largely ignored in most prior studies: First, affect varies across the life span with young adults (i.e., aged 20 to 30 years) reporting particularly low well-being (Carstensen et al., 2011). Thus, evidence for young adults is especially valuable to indicate whether physical activity is an effective means for promoting affect in young adults. Second, how we behave and how we feel is constantly changing from day to day and from situation to situation. Therefore, to infer whether actual physical activity in everyday life goes along with improved affect, a research design that captures naturally occurring physical activity and affect in everyday life is needed. One approach that tries to get closer to real life and to increase ecological validity is *ambulatory assessment* – repeated assessments of the same individuals in real time and in everyday life (Trull & Ebner-Priemer, 2014). Studies using ambulatory assessment can point out how young adults incorporate physical activity in their lives and whether they experience mental health benefits from it, such as improved affect. These results can corroborate previous findings with evidence obtained in real life and lead to practical implications for health promotion.

Beside the advantage of applying ambulatory assessment for investigating the potential of physical activity for improving affect, in a broader perspective it is an advantageous approach for studying fluctuations in physical activity, affect and executive functions in everyday life. One important field for applying ambulatory assessment is the school context. Schools as educational institutions have the aim to consistently foster positive changes in students' academic achievements. Ambulatory assessment can be used to shed light on those learning processes targeted in schools. To date, learning processes are oftentimes evaluated with half-term exams or monthly teacher-reports in daily school practice. In the same vein, most studies assess longitudinal changes in learning processes across years, so far (Hasselhorn, Schneider, & Trautwein, 2014). However, fluctuations in processes related to academic achievement are also naturally occurring in shorter time frames, such as day-to-day changes in physical activity, affect or executive functions. Ambulatory assessment can be applied to investigate these learning-relevant processes in real time in daily school life. Preliminary evidence demonstrates that results from ambulatory assessment studies can inform our understanding of antecedents and consequences influencing academic achievement. These results can broaden our etiological understanding of educational

success. Thus, applying ambulatory assessment in schools is promising and needs to be promoted for a more wide-spread application. Furthermore, beyond the identification and assessment of learning processes, the question of factors that improve those processes arise. One factor potentially contributing to improved learning processes is physical activity.

The potential of physical activity to improve (b) *executive functions* as one aspect of cognitive functioning gains increasing popularity in the media and in science. In this way, authors encourage the general population for instance to "Be smart, exercise your heart" (Hillman, Erickson, & Kramer, 2008, p.58). Executive functions are the cognitive aspect of self-regulation that refers to the regulation of behaviour, cognition, and emotion (Blair & Ursache, 2011). During early childhood (i.e., 4 to 7 years), executive functions develop (Garon, Bryson, & Smith, 2008). Early executive functions are already crucial for learning processes. In this way, young children's executive functions can predict later academic achievement and thus, educational success (Blair & Razza, 2007; Preßler et al., 2014). Therefore, executive functions seem to be a suitable operationalization of cognitive functioning relevant for children's educational success. Studies in adults demonstrate that physical activity interventions can increase subsequent executive functions (Barenberg, Berse, & Dutke, 2011). However, to derive implications for education, the effects of physical activity interventions have to be investigated in children. Given the lack of evidence, standardized intervention studies in young children are highly needed to inform policy makers and educational institutions about the causal effects of physical activity on improved cognitive functioning, such as executive functions.

Taken together, the overarching goal of the present dissertation is to incorporate ambulatory assessment and intervention methods for investigating whether physical activity has the potential to improve affect and executive functions. In addition, the present dissertation reviews the value of applying ambulatory assessment in the school context. To be more precise, the present dissertation undertakes three research endeavours. First, we investigated the association between physical activity and affect in young adults' daily lives by applying the innovative research approach of ambulatory assessment in *Manuscript 1*. Second, we reviewed ambulatory assessment studies and their advantages and challenges for exploring learning processes in school in *Manuscript 2*. Third, we investigated the effectiveness of a physical activity

intervention to improve executive functions in young children by applying a standardized intervention study in *Manuscript 3*.

The present dissertation is structured into four chapters, following this introduction section. Chapter 2 presents the theoretical and empirical background for investigating the potential of physical activity for affect and executive functions and introduces the promising method of ambulatory assessment. Chapter 3 summarizes the resulting research aims. Chapter 4 gives an overview over the three manuscripts. Finally, in Chapter 5 the main findings of the three manuscripts and their implications for research and practice are discussed.

2 THEORETICAL AND EMPIRICAL BACKGROUND

The following sections are dedicated to introduce the theoretical and empirical background of the present dissertation. Section 1.1 introduces physical activity and its assessment in adults and children. In Section 1.2, ambulatory assessment is defined and the advantages and challenges are summarized. Section 1.3 targets the potential of physical activity to improve affect and outlines the advantageous application of ambulatory assessment for this association. Section 1.4 focuses on the potential of physical activity to improve executive functions and presents mechanisms that influence the development of an effective physical activity intervention.

2.1 Physical Activity

Physical activity may have the potential to improve affect and executive functions. Moreover, research on physical activity and its effects on affect and executive functions is highly promising to support health promotion and education. This section introduces the concept and assessment of physical activity and thereby lays the foundation for research on the potential of physical activity, presented in Section 2.3 and Section 2.4. Section 2.1.1 starts with the definition and characteristics of physical activity. Section 2.1.2 focuses on available measures for physical activity. Finally, Section 2.1.3 closes with the transfer of these conceptual and methodological notions to the application within the present dissertation.

2.1.1 Definition of physical activity

Physical activity can be defined as “any bodily movement produced by skeletal muscles that requires energy expenditure” (Caspersen, Powell, & Christenson, 1985, p.126). To describe physical activity, quantitative and qualitative aspects have been identified. Importantly, the effectiveness of physical activity for improving affect and executive functions depends on these aspects. Thus, quantitative and qualitative aspects of physical activity will be specified in the following.

Physical activity is predominantly described with regard to its *quantitative* aspects, such as its (a) duration, (b) frequency, and (c) intensity (Pesce, 2012; Strath et al., 2013). The duration and frequency of physical activity are assessed by recording the (a) time length and the (b) frequency of occurrence (e.g., daily, weekly) of physical activity. With regard to the frequency, the terms of acute and chronic physical activity have been used to distinguish between physical activity performed on a single-occasion and regularly repeated physical activity. The (c) intensity level of physical activity can be described in terms of the energy expenditure that is determined by the "amount of muscle mass producing bodily movements and the intensity, duration and frequency of muscular contractions" (Caspersen et al., 1985, p.127). It can objectively be assessed by various methods, as for instance by recording the duration and frequency of an individual's heart rate or body acceleration. These records can then be referred to an individual's maximal capacity level (i.e., as percentage of maximal aerobic capacity/ oxygen uptake [VO²max]) or to generally valid reference values of energy expenditure (i.e., metabolic equivalent of task [MET]). Thus, the three quantitative aspects of physical activity are used to compute the intensity level of a given physical activity that is specific for an individual or generally valid. Exemplary activities pertaining to different levels of intensity are shown in Table 1.

Table 1 *Physical activity: Classification based on intensity (Ainsworth et al., 1993; Strath et al., 2013)*

Intensity level	VO²max (%)	MET	Exemplary activities
Light	≤ 44	≤ 2.9	walking below 4 km/h; stretching
Moderate	44-59	3.0-5.9	walking with 4-7 km/h; cycling <16km/h; household activities, such as mopping up
Vigorous	≥ 60	≥ 6.0	running with >7km/h; cycling >16km/h; team games, such as basketball, handball

Note. VO²max: maximal aerobic capacity in percent; MET: indicate metabolic equivalents, 1 MET refers to an adult's energy expenditure during rest corresponding to an oxygen uptake of 3.5 ml per kg of body weight per minute (Ainsworth et al., 1993).

Beside those quantitative aspects of physical activity, recently, many claims have been raised to shift also towards the *qualitative* aspects to describe physical activity (Tomporowski, McCullick, Pendleton, & Pesce, 2015; Pesce, 2012), such as its (d) type and structure (e.g., Caspersen et al., 1985) as well as its (e) context (e.g., Kanning, 2013). As depicted in Table 1, physical activity within one intensity level can

vary greatly ranging from cycling to mopping up. Physical activity can be differentiated with regard to its (d) type and structure resulting in spontaneous or unstructured activities, such as household or commuting activities, compared to intended and structured activities, such as *exercise*. Exercise is defined as planned, structured, repetitive physical activity with the aim to improve *physical fitness* (Caspersen et al., 1985, p.128). Physical fitness refers to five health-related components: cardiorespiratory endurance, body composition, muscular strength, muscular endurance, and flexibility, or seven skill-related components: agility, balance, coordination, speed, power and reaction time (Caspersen et al., 1985). Thus, exercise demands can vary depending on which physical fitness component is targeted. Targeting for example the skill-related component coordination requires an exercise to have motor coordination demands, such as bilateral coordination exercises. Motor coordination, in turn, is defined as the interplay between the central nervous system and the muscular system to perform purposeful movement sequences (Neumaier, 2006). Physical activity in everyday life comprises exercise as well as non-exercise activities. Moreover, various definitions of the (e) context of physical activity have been used, as for instance whether physical activity is performed alone or with others (i.e., with whom?; Dunton, Liao, Intille, Huh, & Leventhal, 2015) or during working versus leisure time (i.e., where?; Kanning, 2013).

2.1.2 Assessment of physical activity

To investigate correlates or effects of physical activity, accurate assessments are indispensable. In the following, direct and indirect measures of physical activity are compared. Moreover, physical activity behaviour is different for children and adults and these age-specifics need to be considered in accurate assessments.

Quantitative and qualitative aspects of physical activity can be assessed by indirect or direct measures. *Indirect measures* are self-reports that ask participants to indicate their physical activity behavior. Self-reports can assess quantitative and qualitative aspects, ranging from the duration, frequency and intensity of physical activity and thereby related estimations of energy expenditure to the type and context of physical activity. One of the most commonly used self-report for adults is the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) freely available in short and long form and multiple languages (http://ipaq.ki.se/). In the short form, for instance, participants are asked about the time they spent being physically active in the

last 7 days with regard to different intensity levels. They indicate the frequency (days per week) and duration (minutes per day) they have been physically active in different intensity levels (light, moderate, vigorous). Consequently, the weekly energy expenditure can be estimated by referring to a classification of physical activity to METs (Craig et al., 2003). Self-reports are often used in studies with large sample sizes due to their low costs and easy applicability (Warren et al., 2010). Moreover, they provide the possibility to assess qualitative aspects of physical activity, such as the type and context. However, reliability, sensitivity and validity of self-reports are rather low since responses are often biased by social desirability and the cognitive demands of recall (Warren et al., 2010). In addition, for children, self-reports may be unreliable and parent-reports are often biased resulting in limited validity (Kohl, Fulton, & Caspersen, 2000).

Direct measures of physical activity include wearable motion sensors (e.g., accelerometers), heart rate monitors, direct observation, calorimetry or doubly labelled water (Warren et al., 2010). Direct measures can be called more objective since influences of memory effects and social desirability are ruled out. Importantly, differences between the mentioned direct measures are related to accuracy and costs. The calorimetry or doubly labelled water method, for instance, provide highly precise estimations of the energy expenditure, while these are only applicable under standardized laboratory conditions. Wearable motion and heart rate sensors can assess the duration and frequency of physical activity, while the intensity is assessed by estimating energy expenditure based on sampled raw data of acceleration or heart rate. Accelerometers and heart rate monitors have been shown as valid and accurate measures usable in field and laboratory studies with relatively low costs (Kelly et al., 2013; McMinn, Acharya, Rowe, Gray, & Allan, 2013; Plasqui, Bonomi, & Westerterp, 2013; Strath et al., 2000).

Accelerometers, such as the Actigraph GT3x+ (ActiGraph, 2013) used in *Manuscript 1*, are small devices attached on the waistband with a belt. The GT3x+ assesses acceleration of the trunk along three planes (i.e., horizontal, vertical, and perpendicular axes). Raw data of acceleration is then bandpass-filtered, aggregated into epochs, wear-time validated and transformed into counts per minutes (CPM) based on validated cut-points (e.g., for adults: Sasaki, John, & Freedson, 2011). The cut-points indicate energy expenditure allowing estimations of quantitative aspects of physical activity. Advantageous of the use of accelerometers are the high accuracy and low

participant burden, while the processing of the raw data (e.g., cut-point based categorization) as well as their limitation to accelerations of the trunk excluding for instance strength training or upper body movements can be criticized. Moreover, water-based activities are excluded due to non-waterproof of most accelerometers.

Heart rate monitors can measure electrocardiographic signals to indicate the intensity of physical activity. One example is the ekgMove (Movisens®, Karlsruhe, Germany) used in *Manuscript 3*. It is a small device (62.3 mm × 38.6 mm × 10.5 mm) that can be attached at participant's thorax, at the height of the sternum, with adhesive disposable electrodes. Raw data is aggregated into epochs and transformed into average heart rates per epoch (DataAnalyzer 1.7; Movisens®, Karlsruhe, Germany). Moreover, data validation by removing sampling artefacts is necessary (e.g., removing illogically low or high values; de Bock et al., 2010). One advantage of using heart rate measures is their high accuracy in assessing the intensity level, since heart rate values can be referred to the individual level of the VO^2max. However, oftentimes age-dependent norms of the VO^2max are used (e.g., estimated VO^2max in children = 208 - 0.7× age; Mahon, Marjerrison, Lee, Woodruff, & Hanna, 2010). To accurately assess the heart rate, other factors influencing the heart rate, such as a high ambient temperature or emotional stress (Freedson & Miller, 2000), have to be considered. This could be done by assessing participants' heart rates in the same standardized setting.

Comparisons between indirect and direct measures of physical activity provide strong support for direct measures. One meta-analysis of 173 studies shows only low agreement of self-reports and more objective measures of physical activity, such as accelerometers, in adults (r = .37, SD = 0.25, Prince et al., 2008). To be more precise, the quantitative amount of physical activity that is subjectively reported is often higher than in objective records. The reasons for this difference are still in debate (Bussmann & Ebner-Priemer, 2012) and it could be that self-reports and objective records assess different constructs of physical activity.

Further on, assessments of physical activity have to consider age differences to provide accurate measures. Children and adults differ in the amount and in the way they engage in physical activity: Children in the preschool years engage more often in physical activity than young adults (Sigmund, Ste Croix, Miklankova, & Fromel, 2007). Moreover, in everyday life, children engage often in spontaneous short bouts of physical activity with high variations of intensity (de Bock et al., 2010), whereas adults engage in longer bouts of physical activity with mainly slow changes of intensity. As a

consequence, objective assessments of children's physical activity have to focus on shorter epoch lengths than for adults due to the high variability of physical activity observed in children.

2.1.3 Physical activity as investigated in the present dissertation

Defining physical activity is very helpful for understanding the present research aims and for deriving practical implications. Moreover, preliminary evidence supports the notion that quantitative and qualitative aspects of physical activity have differential effects on mental health, such as affect (Dunn, Trivedi, & O'Neal, 2001), and on cognitive functioning, such as executive functions (Tomporowski et al., 2015). Previous studies highlight for instance the effectiveness of physical activity with moderate-to-vigorous intensity for improving affect (e.g., Langguth, Schmid, Gawrilow, & Stadler, 2016) and of physical activity with motor coordination demands for improving executive functions (e.g., Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008). Consequently, we investigated physical activity in its most promising forms. *Manuscript 1* investigates every moderate-to-vigorous physical activity individuals engage in in during daytime and how this amount of physical activity is associated with affect in everyday life. *Manuscript 3* implements physical activity in form of an exercise intervention with one session of fixed duration, moderate-to-vigorous intensity and motor coordination demands to investigate the causal link between physical activity and executive functions.

Besides, the accuracy of assessments influences the data quality. In line with this, direct and objective assessments of physical activity are claimed as the gold standard for capturing physical activity in everyday life (Trull & Ebner-Priemer, 2013) and overcome the limitations associated with self-reports. Moreover, assessments have to be adapted to participant's age. Consequently, in the studies of *Manuscript 1* and *3* we used direct measures, such as accelerometers and heart rate monitors, in age-appropriate analyses, such as short epoch lengths in children, to assess physical activity. Furthermore, by using direct measures of physical activity that realize repeated assessments within individuals in real time and real life, we applied ambulatory assessment of physical activity in *Manuscript 1* and *3*.

2.2 Ambulatory Assessment

Behavior, such as physical activity, affect and cognitions, such as executive functions, vary across situations and across time. If we consider for instance how we felt yesterday evening compared to the current moment, changes are intuitively observable. Moreover, when thinking back to the weekend, our daily level of physical activity may have been different from a normal working day. Importantly, to investigate these constructs in everyday life, assessment strategies are needed that take into account fluctuations from situation-to-situation or time-point-to-time-point. *Ambulatory assessment* represents one research tool suitable for capturing these fluctuations. Section 2.2.1 introduces ambulatory assessment and its various variants. Section 2.2.2 summarizes the advantages of ambulatory assessment along with challenges. Section 2.2.3 presents two applications of ambulatory assessment within the present dissertation and their benefit for supporting health and education.

2.2.1 Definition and historical development of ambulatory assessment

Ambulatory assessment[1] can be referred to as an umbrella term subsuming research methods that aim at capturing fluctuations within-persons in real time and in real life across a fixed period of time (*Society for Ambulatory Assessment*; Trull & Ebner-Priemer, 2014). Importantly, this definition excludes assessments that are retrospective or take place in experimental laboratories. In addition, one defining characteristic of ambulatory assessment is its *intensive longitudinal design* where closely repeated assessments are taken within the same individuals in their natural environment (Bolger & Laurenceau, 2013). Beside the umbrella term of ambulatory assessment, there exist multiple similar methods, such as experience sampling, ecological momentary assessment, real-time data capture, or daily diaries. These methods can be differentiated by originally distinct research aims and consequently different assessment strategies (Bolger & Laurenceau, 2013; Trull & Ebner-Priemer, 2014). For example, *ecological momentary assessment* is mainly based on multiple self-report assessments per day in the situations of interest via hand-held computers such as

[1] Some authors restrict ambulatory assessment to assessments using portable devices thereby excluding paper-pencil-assessments or online diaries (Fahrenberg, Myrtek, Pawlik, & Perrez, 2007). However, ambulatory assessment can also include these assessment strategies since they may also allow assessments in real life and real time.

personal digital assistants. In contrast, *daily diaries* focus rather on one single assessment per day via paper-pencil or online questionnaires. The research aims and the fluctuations of interest determine the assessment strategies of ambulatory assessment, such as the sampling plan or design and the selection of assessment methods (Fahrenberg, Myrtek, Pawlik, & Perrez, 2007). An overview over six distinguishable assessment strategies is given in Table 2. Assessment strategies can be categorized with regard to their level of structuration, ranging from continuous monitoring without instructions to controlled monitoring restricted to defined settings. In addition, at level 2 of structuration, assessment strategies differ in the way how they signal the participants to take part in one assessment point.

Table 2 *Sampling strategies of ambulatory assessments (adapted from Bolger, 2013, pp.14–21, and Fahrenberg, 2007, pp.208–209)*

Level	Strategy	Synonymous terms	Description	Examples of application
1	*Continuous monitoring*	Ambulatory monitoring	A 'data stream' is continuously assessed without further intervention.	Recording of participant's physical activity with accelerometers across the whole day (e.g., *Manuscript 1*)
2	*Interval-contingent monitoring*	Daily diaries	At predefined time-points, participants have to answer self-reports, solve cognitive tasks or use physiological monitors.	Participants have to answer self-reports of their current affect states before going to sleep (e.g., *Manuscript 1*)
2	*Signal-contingent monitoring*	Experience sampling, ecological momentary assessment	When prompted by the researcher, participants have to answer self-reports, solve cognitive tasks or use physiological monitors.	Participants have to answer self-reports when hearing an acoustic signal on their smartphone.
2	*Event-contingent monitoring*		Every time a predefined event has taken place, participants have to answer self-reports, solve cognitive tasks or use physiological monitors.	Participants have to indicate their current affect after having had a social interaction for at least 10 minutes.
2	*Device-contingent monitoring*	Interactive monitoring, context-aware experience sampling	Real-time analyses of recordings trigger participants to answer self-reports, solve cognitive tasks or use physiological monitors.	An increase in participant's heart rate leads to prompting this participant to indicate his/her current affect state.
3	*Controlled/ structured monitoring*		Recording is restricted to predefined natural or arranged settings.	Participants are asked about their current affect in their working time and during leisure time.

Ambulatory assessment can refer to various assessment methods ranging from self- or third-party reports (e.g., questionnaires) to direct and more objective measures of behavior (e.g., accelerometers), as indicated in Table 2. Importantly, to ensure assessment quality, the standards of psychological testing have to be fulfilled. This means that reliability, validity, and objectivity have to be tested for any measure used in the specific case of repeated assessments in everyday life (Hubley & Zumbo, 2013; Shrout & Lane, 2012).

Historically, psychological research applying ambulatory assessment can be dated back to Wilhelm Wundt (Wilhelm, Perrez, & Pawlik, 2012). As early as 1882, Hodges conducted a case study in everyday life by using pedometers to objectively assess physical activity at the working place (Wilhelm et al., 2012). In the 1940's, social psychologist Allport emphasized that "Psychology needs to concern itself with life as it is lived" (1942, p. 56) and requested to sample consecutive and comprehensive documentations of everyday life. Subsequently, larger ambulatory assessment studies uncovered meaningful phenomena that have been latent in conventional laboratory studies or even contradicted results obtained in the laboratory (e.g., Buse & Pawlik, 1984). In the 1980's, advancements in the technological domain (e.g., hand held computers; Fahrenberg et al., 2007) and in statistical analyses (e.g., multilevel modeling; Bryk & Raudenbush, 1987) supported the application of ambulatory assessments. During the last 10 years an exponential increase of ambulatory assessment studies has been documented (Bolger & Laurenceau, 2013). Today, the wide spread usage of smartphones and monitoring devices in everyday life (e.g., pedometers, pulse monitors; Statista Survey, 2016) further supports the acceptance and feasibility of ambulatory assessment studies. Nevertheless, the actual application of ambulatory assessment in psychological research lags far behind its potential (Fahrenberg et al., 2007).

2.2.2 Advantages and challenges

The defining characteristics of ambulatory assessment – to repeatedly assess the same individuals in real time and real life – result in its three main advantages: (a) ecological validity, (b) within-person perspective, and (c) accuracy of measures.

First, ambulatory assessment allows assessing phenomena as they naturally occur in real life (Reis, 2012). In this way, events can be investigated that cannot be induced due to ethical or pragmatical reasons, changes in behavior over time can be observed as they naturally unfold across time, and the context of sampling can be chosen to resemble participant's natural environment. As a consequence, results from ambulatory assessment studies can possibly be more ecologically valid than results from laboratory studies, thus supporting inferences to participant's real lives.

Second, ambulatory assessment offers the possibility to investigate processes on a within-person level where the same individuals are compared across time. This leads

to describe individual's behavior or experiences not only as stable dispositional *traits* but also as time- or context-dependent *states*. Importantly, changes across situations and times occur naturally in everyday life and can serve as antecedents, correlates or consequences of phenomena. As for instance, affect variability has been demonstrated to be linked to risky health behavior (Weinstein, Mermelstein, Shiffman, & Flay, 2008). In addition, results obtained on a between-person level, that compares different individuals at one time point as in cross-sectional studies, cannot be transferred to the within-person level and may even be opposing (Hamaker, 2012). It is only under the conditions of ergodicity – homogeneity and stationarity – that a transfer of results from the between-person level to the within-person level is valid (Molenaar & Campbell, 2009). In this case, the data should have invariant statistical characteristics across subjects (i.e., homogeneity) and across time (i.e., stationarity; Molenaar & Campbell, 2009, p.113). However, experiences and behavior are mostly person-specific variables that reflect non-ergodic processes. Thus, ambulatory assessment provides insight into within-person processes that enrich empirical psychological research and cannot be replaced by other methods.

Third, by conducting assessments in real time ambulatory assessment supports the accuracy of its measures. In this way, measures can assess experiences, cognitions or behavior in the actual moment they appear. This avoids biases that commonly appear in self-report measures due to their retrospective nature and the influences of characteristics of memory storage (Schwarz, 2012). More precisely, retrospective reports on affect experiences and behavior do not converge with concurrent momentary reports and it is assumed that participants cannot validly respond to these reports. In addition, ambulatory assessment enables the application of direct measures in real time, such as accelerometers to assess physical activity behavior in everyday life. Combining measures of multiple sources, such as self-reports and physiological measures, can offer a comprehensive picture about real-time processes in everyday life (Ebner-Priemer & Trull, 2009).

Ambulatory assessment opens up multiple advantages along with challenges. Importantly, researchers have to take up the following four challenges: (a) participant's compliance, (b) methodological knowledge, (c) participant's reactivity to assessments, and (d) ethical issues. First, when assessing the same individuals repeatedly, motivation to participate may lessen across time and this may require the implementation of token economies and handling of missing data. Moreover, some participants may not adhere

to the study instructions, as for instance by not filling out diaries on a daily level, but collectively on one day. To identify invalid data, electronically registered time stamps can be useful. Electronic devices are also preferable to paper-pencil measures due to their possibilities of prompting ("beep") and adaptive testing (Fahrenberg et al., 2007). Second, for the application of ambulatory assessment knowledge about psychometrics and statistical analyses is indispensable (Shrout & Lane, 2012; Singer & Willett, 2003). As for instance, measures have to reliably detect change and analyses have to consider multiple levels, such as the within- and between-person level. Third, repeated assessments in participants' everyday lives can evoke reactivity (Barta, Tennen, & Litt, 2012). Reactivity to assessments as indicated by time trends and systematic patterns of missing data has to be taken into account when analyzing ambulatory assessment data. Fourth, ambulatory assessment requires to consider ethical issues in particular with regard to participant's burden (e.g., intrusiveness of the assessment strategy), data storage (e.g., on the device or wireless transfer to server) and content of assessments (e.g., voice recording of every social interaction).

2.2.3 Ambulatory assessment as applied in the present dissertation

Given the advantages of ambulatory assessment it seems as a highly valuable research tool for discovering phenomena in everyday life. The present dissertation sheds light on the application of ambulatory assessment for (a) investigating the potential of physical activity to improve affect and for (b) investigating fluctuating processes in the school context.

First, daily physical activity is recommended by national and international associations for ensuring mental health, such as affect. Ambulatory assessment studies investigating the association between naturally occurring physical activity and affect, as in *Manuscript 1*, can further enrich these recommendations with evidence obtained in everyday life. In addition, the results of this study may corroborate evidence-based recommendations and thus support health promotion.

Second, schools as educational institutions have the aim to consistently foster changes in students' academic achievements, that is learning processes. Ambulatory assessment can be applied to investigate these learning processes in real time and in daily school life. This will further lead to identify antecedents and consequences influencing learning processes and educational success. Thus, *Manuscript 2* of this

dissertation highlights the advantages and challenges by reviewing studies that applied ambulatory assessment for investigating daily school life.

2.3 Physical Activity and Affect in Young Adults

One great potential of physical activity is its positive influence on well-being, such as affect. Investigating the association between physical activity and affect can inspire programs for health promotion. Section 2.3.1 emphasizes the importance of studying affect and then focuses on conceptual and theoretical approaches as well as corresponding assessment strategies of affect. Section 2.3.2 identifies gaps in the existing literature on the association between physical activity and affect in everyday life and highlights further important and innovative research endeavours. Section 2.3.3 summarizes the mechanisms underlying the association between physical activity and affect. Finally, Section 2.3.4 outlines the conclusions that are derived for studying the association between physical activity and affect in the present dissertation.

2.3.1 Relevance, definition and theories of affect

Why is it relevant to investigate affect? Affect is important for mental and physical health. In detail, evidence from longitudinal studies and randomized control trials supports the notion that enhanced affect (i.e., more positive and less negative affect) causes improved health, as for instance greater longevity (Diener & Chan, 2011). Moreover, some studies in everyday life indicate that affect states are associated with mental and physical health. Positive affect states in everyday life have been found to be associated with, for instance, better immune functioning (Cohen, Doyle, Turner, Alper, & Skoner, 2003). Negative affect states were associated with increased activation of the hypothalamic-pituitary-adrenal axis that implies, for instance, an elevated vulnerability for psychiatric disorders (Jacobs et al., 2007). Importantly, young adults (aged 20 to 30 years) have been found to report less positive affect and more negative affect than in later adulthood (Stone, Schwartz, Broderick, & Deaton, 2010; Carstensen et al., 2011). Given the strong relation between affect and health, young adults may represent a specific target group of affect-enhancing interventions for health promotion.

Affect refers to “a neurophysiological state that is consciously accessible as a simple, nonreflective feeling” (Russell, 2003, p.147) and represents a transient episode

readily changeable by contexts (Cranford et al., 2006). Important characteristics of affect include (a) its non-reflective character, meaning that affect does not necessarily result from preceding cognitive appraisals and is not directed on an eliciting stimulus, and (b) its transient character referring to the variable nature and intensity of affect across time. In addition, affect is constantly present and can also occur as a component of mood and emotion (Ekkekakis, 2013). In the literature, the terms affect, mood and emotion are sometimes used interchangeably, but there are important differences between these constructs, as shown in Table 3. *Mood* is defined as an "an affective state of long duration, low intensity, and a certain diffuseness" (Frijda, 2009, p.258). Thus, affect and mood can be differentiated by their duration, as affect reflects a transient feeling at one single moment and as mood lasts longer. Affect can vary in its intensity, whereas mood is low intense. Moreover, affect is conceptualized as not directly elicited by a stimulus, whereas mood can have a vague object or cause. *Emotion* refers to a short, highly intense feeling directly elicited by a cognitively appraised stimulus and accompanied by bodily reactions (Ekkekakis, 2013). So, affect and emotion can be differentiated in particular based on their duration and their relatedness to a stimulus.

Furthermore, affect can be conceptualized as trait or state. Affect traits refer to dispositional patterns of experiences that are stable over time, whereas affect states are momentary, transient, and context-dependent episodes of feelings (Brose, Voelkle, Lövdén, Lindenberger, & Schmiedek, 2014). Thus, for assessing affect as a trait individuals are asked about their typical affect during extended time periods and for assessing affect states individuals indicate their current affect. When aiming at capturing transient episodes of feelings in everyday life, affect states seem to be the construct of interest.

Table 3 *Tentative distinction between affect, mood and emotion (adapted from Ekkekakis, 2013, pp.47–48)*

Dimension	Affect	Mood	Emotion
Frequency	always	much of the time	rarely
Duration	constant	long (i.e., hours to days)	short (i.e., seconds to minutes)
Intensity	variable	low	high
Object/Stimulus	not necessarily	yes, but may be unspecific	yes, specific eliciting stimulus
Examples	pleasure, tiredness	dysphoria, grumpiness	guilt, jealousy

Affect theories can be classified into (1) dimensional and (2) categorical approaches (Ekkekakis, 2013). Dimensional theories assume that each affect can be modeled as a combination of basic dimensions. One prominent example is Russell's circumplex model that postulates two orthogonal dimensions: (a) valence or pleasure and (b) activation or arousal (Russell & Barrett, 1999; Posner, Russell, & Peterson, 2005), as depicted in Figure 1.

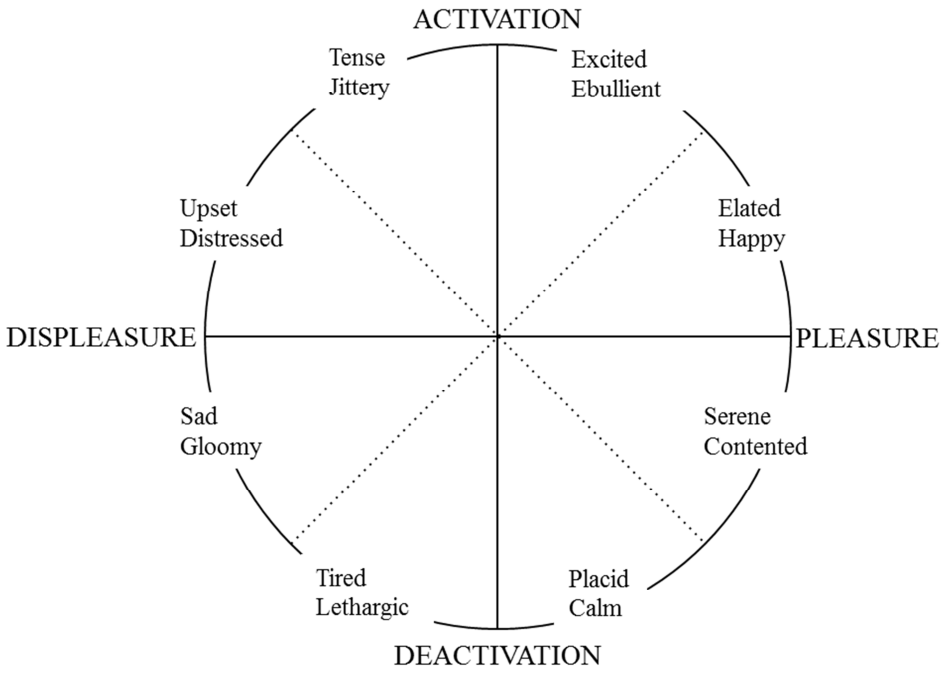

Figure 1. Circumplex model of affect (Russell, 2003, p.148).

Each dimension has two bipolar endpoints (pleasure - displeasure, activation - deactivation). Combining these two dimensions puts up various affect states and thus allows capturing a wide scope of affect. Affect states that are closer together in one sector share resembling degrees of valence and activation. Importantly, some of these affect states do not purely denote affect when defining it as non-cognitive, since they also contain some cognitive appraisal. For instance, *upset* implies to be angry with something and is strictly speaking an emotion. Nevertheless, upset also contains unpleasant-deactivated affect and this is the reason why it is included in the circumplex model. In this way, pure states of affect are located on the axes of the dimensions, whereas affect states with emotional quality are located on the circumplex (i.e., perimeter of a circle; Russell & Barrett, 1999). Based on the circumplex model it is not possible to differentiate between some of these affect states, such as anger and fear. In

this specific case, both states share the same underlying unpleasant-activated affect, but stem from different preceding cognitive appraisals (Russell & Barrett, 1999, p.807).

A more nuanced picture of affect is provided by (2) categorical affect theories. Categorical theories assume that each affect represents one distinct state (Izard, 1993). Some authors also postulate categories formed of resembling distinct affect states (Ekkekakis, 2013). One advantage of the categorical approach is the possibility to investigate affect in a specific way. Further on, specific affect states also provide higher intuitive comprehension than dimensional affects since individuals merely experience pure states of affect (such as valence or activation) and natural affect experiences rather reflect affect states with emotional quality located on the circumplex (such as *sad* or *tired*, see Figure 1). The set of distinct affect states should be selected in each study with respect to the research questions. Since the set of distinct states that is studied may appear to be arbitrary, it is necessary to justify the rationale of affect selection.

Combining the dimensional and categorical approach benefits from the advantages of both approaches and is also claimed by authors of the dimensional approach (Russell, 2003, p.150). Hierarchical models combine both approaches and assume that affect dimensions refer to a higher level and distinct states are grouped on a lower level beneath them (Ekkekakis, 2013). Moreover, combining both approaches can support theoretical considerations when selecting a measure that fits to the research aims. This argument will be illustrated with an example. The research aim is, for instance, to assess how physical activity is associated with a wide range of specific affect states. One example of a measure related to distinct states is the Profile of Mood[2] States (original: POMS, McNair, Lorr, & Droppleman, 1992; shortened adaption: POMS-15, Cranford et al., 2006). It consists of items referring to five distinct categories of affect: depression, anger, anxiety, fatigue, and vigor. From the perspective of the circumplex model, these categories cover only three of four sectors: unpleasant-deactivated affect by depression and fatigue, unpleasant-activated affect by anger and anxiety, and pleasant-activated affect by vigor. Items are missing that address pleasant-deactivated affect, such as serenity. Consequently, given the research aim to investigate a wide range of affect and specific affect states at the same time, the POMS-15 can be enriched by including, for instance, additional items of serenity. Besides these

[2] In the original version of the Profile of Mood States (McNair, Lorr, & Droppleman, 1992) participants are instructed to answer how they felt during the last week including today, thus measuring longer lasting mood states, whereas a transfer to assess affect can be reached by reframing the instruction and by asking the participants how they currently feel (Cranford et al., 2006).

theoretical considerations, the selection of an adequate affect measure should certainly also consider its psychometric quality (Hubley & Zumbo, 2013; Shrout & Lane, 2012).

2.3.2 Gaps in the literature on the association between physical activity and affect in everyday life

Evidence from multiple cross-sectional studies favours a positive association between physical activity and affect in the way that more active participants report enhanced affect compared to less active participants (e.g., Poole et al., 2011). Fewer longitudinal and intervention studies are available that allow temporal or causal inferences of this association. These studies demonstrate that physical activity can lead to improved affect in community (Conn, 2010; Mammen & Faulkner, 2013; Reed & Buck, 2009; Rethorst, Wipfli, & Landers, 2009) and clinical adult samples (Rimer et al., 2012). Based on these findings, international and national recommendations advise adults to perform 30 minutes of moderate-to-vigorous physical activity on five days per week to ensure health maintenance (American Heart Association, 2016; European Working Group, 2008). However, results from cross-sectional studies do not allow a direct transfer on within-person associations in daily life (Molenaar & Campbell, 2009; see Section 2.1.2). Moreover, despite the value of experimental and intervention studies for causal inferences, they often lack ecological validity. Thus, it still remains unclear whether naturally occurring physical activity performed in everyday life has the same effect on affect as physical activity in form of structured supervised interventions. To investigate whether fluctuations in daily physical activity and affect covary on a within-person level, ambulatory assessment studies with an intensive longitudinal design (as defined in Section 2.2.1) are needed. These results may further corroborate physical activity recommendations with evidence obtained in everyday life.

To date, evidence from ambulatory assessment studies on the association between physical activity and affect is limited. One meta-analysis indicates that physical activity in everyday life is linked to increased positive affect within the subsequent hours ($n = 8$ of 11 studies), but not consistently to less negative affect ($n = 2$ of 4 studies; Liao, Shonkoff, & Dunton, 2015). The null findings for negative affect, also found in further studies (Giacobbi, Hausenblas, & Frye, 2005; Kanning, Ebner-Priemer, & Schlicht, 2015; Mata et al., 2012; Schwerdtfeger, Eberhardt, & Chmitorz, 2008; Wichers et al., 2012) may be attributed to methodological challenges, such as change-

insensitive measures of negative affect, reliance on self-reported physical activity or the selected time-frame of subsequent hours. As a consequence, studies using sensitive affect measures to detect daily changes in negative affect, objectively recorded physical activity to reliably and validly assess physical activity in everyday life, and longer time frames to capture also more distal effects may provide other results. In this way, two studies in adolescents reported associations between the amount of daily recorded physical activity and less depressed affect in the same-day's evening (Gawrilow, Stadler, Langguth, Naumann, & Boeck, 2016) and next-morning (Langguth et al., 2016). However, further replication of these findings in adults is needed.

Moreover, to draw conclusions about how physical activity in everyday life is associated with specific affect states, evidence is limited. The studies mentioned so far refer often to either positive or negative affect (e.g., Langguth et al., 2016) and leave out positive or negative affect with varying activation levels (such as angry vs. depressed affect, e.g., Mata et al., 2012; Schwerdtfeger et al., 2008; Wichers et al., 2012). Evidence on the association between physical activity and specific affect states is advantageous due to its high intuitive comprehensibility as compared to dimensional affect measures. Moreover, studying naturally occurring physical activity and its association to affect will extend previous findings of experimentally manipulated physical activity. Studies assessing physical activity objectively in everyday life and adopting a differential perspective on affect may, thus, further contribute to corroborate physical activity recommendations and support health promotion.

2.3.3 Mechanisms underlying the impact of physical activity on affect

How does physical activity cause enhanced affect? Few prior experimental human and animal studies contributed to answer this question. Consequently, to date, the underlying mechanisms linking physical activity and enhanced affect in the short and long term have not been clearly identified yet (Biddle & Mutrie, 2008). So far, the debate revolves around two pathways: (a) physiological processes and (b) psychological processes (Lehnert, Sudeck, & Conzelmann, 2012; Paluska & Schwenk, 2000; Wolf & Hautzinger, 2012).

First, following the physiological pathway, physical activity may improve affect by the increased release of monoamines (e.g., dopamine, serotonin), opioids (e.g., endorphins; Biddle & Mutrie, 2008) or the brain-derived neurotrophic factor (BNDF;

Knaepen, Goekint, Heyman, & Meeusen, 2010; Mata, Thompson, & Gotlib, 2010). Associations between these neurotransmitters and proteins have been shown for negative affect (e.g., Lee, Jeong, Kwak, & Park, 2010) and positive affect (Dishman & O'Connor, 2009). Moreover, improved neuroimmune modulation (Eyre & Baune, 2012) and favorable changes in the brain's blood circulation (Dietrich & Audiffren, 2011) have been discussed to account for the effects of physical activity on affect.

Second, following the psychological pathway, physical activity may lead to improved affect via increases in global self-esteem (Spence, McGannon, & Poon, 2005) or self-efficacy (Netz, Wu, Becker, & Tenenbaum, 2005). Moreover, engaging in physical activity may work as a distraction from negative events and thoughts or strengthen social support if performed with others (Paluska & Schwenk, 2000). Thus, psychological processes provide further explanations for the activity effects on negative and positive affect.

In sum, there are different hypothesized mechanisms for explaining the effects of physical activity on affect. A *biopsychosocial model* including joint influences of physiological and psychological processes underlying the effects of physical activity on affect seems most plausible (Paluska & Schwenk, 2000). However, our understanding of the interplay between these mechanisms linking physical activity to affect is still in its infancy. Given the limited evidence available for the association between physical activity and specific affect states, future observational studies investigating these effects may settle for experimental research on the underlying mechanisms.

2.3.4 Ambulatory assessment study in the present dissertation

As highlighted in the preceding sections, affect is relevant for physical and mental health and especially low during young adulthood. In addition, physical activity has the potential to improve affect, while the mechanisms are still in debate. However, previous evidence is often based on between-person comparisons and has multiple methodological limitations, such as reliance on self-reported physical activity or insensitive affect measures. To investigate whether physical activity is associated with specific affects in everyday life, ambulatory assessment studies are needed. These offer high ecological validity by measuring what actually happens in everyday life. In addition, relying on accurate measures will circumvent previous pitfalls. Thus, an ambulatory assessment study in young adults across 10 days was conducted using

objectively recorded physical activity and specific affect assessments and is described in *Manuscript 1*.

2.4 Physical Activity and Executive Functions in Children

The potential of physical activity is not restricted to improved affect, but may also include improved cognitive functioning, such as executive functions. This section is dedicated to introduce executive functions as well as theoretical and empirical underpinnings for the effects of physical activity on executive functions. Section 2.4.1 defines execute functions and highlights their importance in early childhood. Section 2.4.2 summarizes gaps in the literature on the effectiveness of physical activity interventions for improving executive functions in children. Section 2.4.3 presents mechanisms underlying the effects of physical activity on executive functions. Further on, implications about the characteristics of effective physical activity interventions are derived. Section 2.4.4 introduces the idea of individual differences that moderate the effectiveness of physical activity interventions and Section 2.4.5 concludes with the application of a physical activity intervention within the present dissertation.

2.4.1 Executive functions and their importance in early childhood

Self-regulation enables individuals to exert goal-directed behavior and comprises the regulation of behavior, cognition, and emotion (Blair & Ursache, 2011). *Executive functions* represent the cognitive aspect of self-regulation and support successful self-regulation (Hofmann, Schmeichel, & Baddeley, 2012). Evidence in adults favors a separation of executive functions into three components: (a) inhibition, (b) updating, and (c) shifting (Miyake et al., 2000). To be more precise, inhibition refers to deliberately inhibit prepotent or automatic responses and also includes resistance to distractors. Thus, inhibition is crucial to exert goal-directed behavior, as it supports to resist to interfering external stimuli, emotions or behavioral habits (Diamond, 2006). Updating can be defined as constant monitoring and manipulation of working memory representations. Shifting refers to flexible shifting between different tasks or mental sets (Miyake et al., 2000). Most studies in childhood also assume the same three correlated but separable components of executive functions (Diamond, 2006; Garon et al., 2008; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003). The development of executive functions

starts in early childhood and is characterized by important changes during the preschool years (i.e., 4 to 7 years; Garon et al., 2008; Romine & Reynolds, 2005). For instance, large improvements in executive function performance are especially observable in preschool children compared to older children (Röthlisberger, Neuenschwander, Cimeli, & Roebers, 2013). In a systematic review, Garon, Bryson, and Smith (2008) present evidence for the developmental pathway of children's executive functions. Selective attention, the ability to focus on a task and ignore irrelevant information, seems to be a prerequisite for the development of executive functions. At the age of 15 months, updating becomes apparent followed by inhibition around 2 years of age and shifting around 3 years of age. Despite these first early appearances of executive functions, the following preschool years are pivotal as executive functions continue to improve considerably (Carlson, 2005; Garon et al., 2008). The physiological foundation of executive functions is the frontal lobe of the brain (Miyake et al., 2000). The fast development of executive functions during the preschool years runs parallel to the development of the frontal lobe, while the maturation of the frontal lobe proceeds into early adulthood (Romine & Reynolds, 2005).

Executive functions, as cognitive aspects of self-regulation, are indispensable for social and academic functioning and play an important role already in early years of life. Evidence highlights the predictive power of executive function performance in preschool children for their successful transition from kindergarten to school, such as adaptive classroom behavior (Blair, 2002; Petriwskyj, Thorpe, & Tayler, 2005; Suchodoletz, Trommsdorff, Heikamp, Wieber, & Gollwitzer, 2009), and academic achievement over and above general intelligence and precursor skills (Blair & Razza, 2007; Preßler et al., 2014). Studies have shown that inhibition in particular is predictive for later social functioning, such as cooperative behavior (Ciairano, Visu-Petra, & Settanni, 2007), and associated with early academic achievement, such as early mathematical and verbal skills (Allan, Hume, Allan, Farrington, & Lonigan, 2014; Blair & Razza, 2007). In light of this evidence, executive functions seem to lay the foundation for children's social and academic success (Ursache, Blair, & Raver, 2012). Consequently, early interventions targeting the improvement of executive functions, especially inhibition, seem to be highly relevant.

2.4.2 Gaps in the literature on the effectiveness of physical activity interventions for executive functions in young children

Interventions for children that target executive functions range from cognitive trainings or holistic curricula in kindergarten to leisure activities, such as physical activity (Diamond & Lee, 2011). Physical activity interventions appear as one promising approach for improving executive functions in children (Best, 2010). Compared to other interventions, such as cognitive trainings, physical activity interventions have the advantage to be low cost, easily accessible, and to yield additional positive effects on children's physical health (Janssen & Leblanc, 2010). Physical activity interventions have been shown to improve executive functions as evidenced by meta-analyses in adults (Barenberg et al., 2011; Chang, Labban, Gapin, & Etnier, 2012; Lambourne & Tomporowski, 2010) and especially in older adults (i.e., mean age ≥ 60 years, Colcombe & Kramer, 2003), while fewer studies are available in children (Best, 2010; Fedewa & Ahn, 2011; Sibley & Etnier, 2003; Verburgh, Konigs, Scherder, & Oosterlaan, 2014). Importantly, these meta-analyses include physical activity interventions with varying frequencies. *Acute* single-bout interventions (e.g., Chang, Liu, Yu, & Lee, 2012) can be distinguished from *chronic* regularly, repeated interventions (e.g., Colcombe & Kramer, 2003). Acute interventions are especially advantageous as their implementation is more feasible in the standardized experimental setting but also in the school context and requires lower costs than chronic interventions. For instance, Verburgh and colleagues showed a moderate effect of acute physical activity to improve subsequent executive functions in 6- to 35-year-old participants (d = 0.52, 95%-CI = 0.29-0.76, n = 19 studies). However, as shown here, effect sizes vary considerably across intervention studies. This variation claims for considering crucial influences, such as the age of intervention recipients.

Improving executive functions with physical activity seems to be especially promising in early years. Important developments of executive functions take place during the preschool period (Romine & Reynolds, 2005) and executive functions have been shown as predictive for future social and academic functioning (Ursache et al., 2012; see Section 2.4.1). While studies are missing that directly tested the moderating effect of age for the association between physical activity and executive function (Best, 2010), one meta-analysis indicates that younger children (i.e., 4 to 7 years) benefit in particular from physical activity interventions by showing improved cognitive functioning compared to older children (i.e., 14 to 18 years; Sibley & Etnier, 2003).

Thus, the preschool age may be an important period to be targeted by physical activity interventions. So far, studies investigating the effect of acute physical activity on executive functions in young children are scarce and show mixed results. Two studies did not find physical activity effects on inhibition compared to sedentary control conditions in young children (Palmer, Miller, & Robinson, 2013; Stein, 2016), while improved attention processes were found in one study (Palmer et al., 2013) but not in another study (Mierau et al., 2014). Consequently, to date, evidence-based recommendations whether physical activity enhances executive functions in young children are not inferable.

2.4.3 Mechanisms underlying the impact of physical activity on executive functions

Given the large variation of effect sizes of prior studies, theories about the underlying mechanisms mediating the effects of physical activity on executive functions may further elucidate this issue. Consequently, this section introduces the most compelling but still discussed mechanisms. In addition, based on the assumed mechanisms the characteristics of an effective intervention will be inferred.

To date, it is still in debate how physical activity improves executive functions in children (Sibley & Etnier, 2003). Nevertheless, given the evidence so far, the mechanisms can be classified into (a) physiological processes and (b) learning and developmental processes (Sibley & Etnier, 2003). These two pathways are not exclusive but complementary.

First, the physiological pathway is based on physiological and chemical processes in the body and brain that are released by physical activity. Studies in adults have shown that physical activity induces physiological arousal leading to an increased cerebral blood flow in the prefrontal cortex, an increased release of brain neurotransmitters, like norepinephrine and dopamine, and of the brain-derived neurotrophic factor (Hötting & Röder, 2013; Winter et al., 2007). These physiological activity derivates may, in turn, facilitate the brain's resource allocation necessary for executive function performance (e.g., Barenberg et al., 2011). Moreover, the amount of physiological arousal induced by physical activity depends on the intensity level of physical activity. Following an inverted U-relationship between intensity and arousal (Yerkes & Dodson, 1908) moderate-to-vigorous physical activity has been shown to be

most effective for increasing the cerebral blood flow (Moraine et al., 1993) as well as for improving speed of processing (McMorris & Hale, 2012). Based on the assumption, that the physiological arousal elicits resource allocations supporting executive functions, moderate-to-vigorous physical activity should be most effective for improving executive functions. Importantly, the mentioned evidence for this mechanisms stems from adult studies. To date, studies in children that are designed to compare different intensity levels of acute interventions are missing. However, some support for this mechanism can be derived from studies that showed benefits of moderate-to-vigorous physical activity compared to sedentary conditions (Ellemberg & St-Louis-Deschênes, 2010; Gawrilow et al., 2016; Hillman et al., 2009). Thus, moderate-to-vigorous physical activity seems to be effective for improving executive functions in children.

Second, the learning pathway is based on developmental and embodied cognition theories. They explain the effects of physical activity on cognitive improvements in children by referring to the bodily interactions and movements in space that accompany each physical activity (Piaget & Aebli, 1974; Wilson, 2002). Piaget (1974) states that children learn concepts and skills by engaging in physical activity and can transfer these acquisitions to the cognitive domain. Moreover, children may learn cause and effect through movements intended to reach a goal (Davis & Lambourne, 2009). In line with these theoretical assumptions, motor and cognitive skills have been found to be especially associated during early childhood while this association seems to decline with age (Voelcker-Rehage, 2005). Further support stems from neurophysiological studies demonstrating a close interrelation between the cerebellum, activated during complex motor tasks, and the prefrontal cortex, activated during executive function tasks (Diamond, 2000; Serrien, Ivry, & Swinnen, 2007). Moreover, the level of learning processes engendered by physical activity may depend on the type of physical activity. Non-automatic, complex or novel physical activity – thus, including *cognitive engagement* – may evoke more learning processes than automatic, simple or repetitive physical activity (Tomporowski et al., 2015). So far, most acute intervention studies in children and adolescents used repetitive, automatic physical activity without cognitive engagement, such as walking on a treadmill or cycling on an ergometer in a laboratory setting (e.g., Hillman et al., 2009). To date, few studies have implemented a cognitively engaging physical activity intervention and these revealed mixed results (Budde et al., 2008; Best, 2012; Jäger, Schmidt,

Conzelmann, & Roebers, 2014; Jäger, Schmidt, Conzelmann, & Roebers, 2015). In line with the hypothesis of the learning pathway, physical activity with motor coordination demands have been found to benefit cognitive functioning more than physical activity without additional demands in adolescents (Budde et al., 2008) and more than a sitting condition in children (Jäger et al., 2014). However, two studies did not find an advantage of a physical activity intervention with cognitive engagement compared to a mere physical activity intervention (Best, 2012; Jäger et al., 2015). Importantly, Budde and colleagues (2008) as well as Jäger and colleagues (2014) implemented their physical activity interventions in an applied setting (i.e., group setting at school) where numerous confounds (e.g., social interaction) cannot be controlled for as compared to a standardized laboratory-based setting (Best, 2012). Consequently, to investigate whether physical activity with cognitive engagement improves executive functions, further controlled laboratory-based studies are indispensable.

Taken together, despite the persisting debate about the mechanisms, it appears as if physical activity improves executive functions via physiological and developmental processes. These pathways differ in their assumptions of which kind of physical activity may be most effective for improving executive functions, as depicted in Figure 2. Consequently, when developing an effective intervention both pathways and their respective implications should be considered. Physical activity interventions with moderate-to-vigorous intensity and motor coordination demands seem most promising for improving executive functions in children.

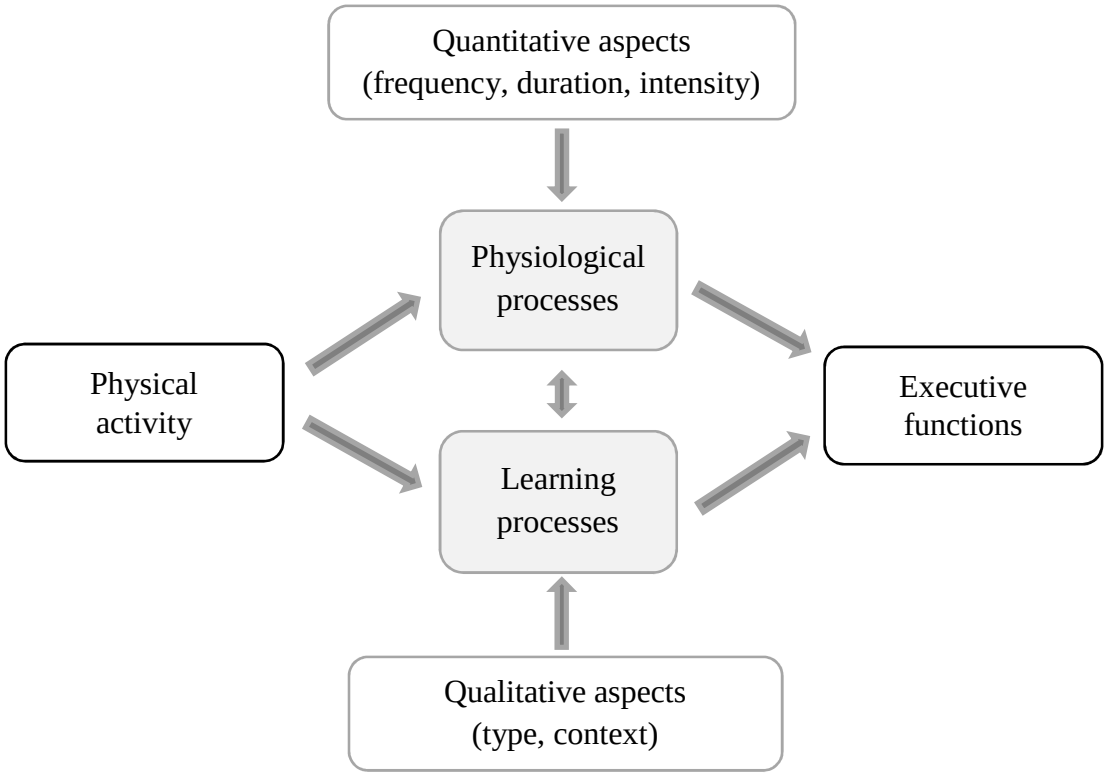

Figure 2. Working model to explain the effects of physical activity on executive functions with moderating influences of aspects of physical activity (self-developed).

2.4.4 Individual differences as moderators

Prior studies have mostly ignored individual differences in physical activity experiences when investigating the acute physical activity effects on executive functions (Pesce, 2009). However, when looking for example at the mixed findings of physical activity interventions with cognitive engagement on improving executive functions (Budde et al., 2008; Best, 2012; Jäger et al., 2015), characteristics of intervention recipients, such as physical activity experiences, may have moderated the physical activity effects.

Theoretically, it is argued that the effects of physical activity on executive functions are moderated by the interplay between intervention demands and individual's physical activity experiences (Pesce, 2009). Derived from the literature on motor learning (Guadagnoli & Lee, 2004), the best effects on executive functions are assumed when physical activity is performed at the *optimal challenge point* where the demands of physical activity match with the individual's ability level (Pesce, 2009). Following

the two pathways mediating the effect of physical activity on executive functions (see Section 2.4.3) different hypotheses can be inferred for the optimal challenge point.

In line with the physiological pathway, the intensity level of physical activity has to match with the individual aerobic fitness level[3]. Indeed, preliminary evidence supports the notion that the aerobic fitness level moderates the effect of physical activity on executive functions (Heckler & Croce, 1992; Jäger et al., 2015). For example, Jäger and colleagues (2015) found that only highly fit children (i.e., 10 to 12 years old) showed improved executive functions after a physical activity intervention compared to a non-physical intervention, while low fit children showed no difference in executive functions.

With respect to the learning pathway, an optimal challenge point is reached when the motor coordination demands of physical activity match with the individual motor coordination experiences. Importantly, motor coordination experiences characterize physical activity behavior in particular in young children (de Bock et al., 2010; see Section 2.1.2). Two studies allow inferences about the moderating influence of motor coordination. First, adolescent elite athletes benefitted more from a physical activity intervention with motor coordination demands with respect to improved attention than from a physical activity intervention without motor coordination demands (Budde et al., 2008). Thus, individuals with high motor coordination skills seem to benefit more with respect to improved cognitive functioning when the physical activity demands correspond to their expert level. In addition, children with deficits in motor coordination or suffering from developmental coordination disorder (ICD-10: F82; WHO, 1992) benefitted more from a chronic physical activity intervention with low cognitive engagement, while normally developing children benefitted more from a chronic physical activity intervention with high cognitive engagement in showing improved attention. It could be assumed that the two groups have different optimal challenge points. While the motor coordination level of the physical activity intervention with high cognitive engagement may have matched optimally for the normally developing children, the children with motor coordination deficits may have been overtaxed and thus, benefitted only from the physical activity intervention with

[3] The aerobic fitness level refers to the cardiorespiratory endurance component of fitness (see Section 2.1.1) and can be assessed via endurance-oriented tasks and the thereby estimated maximal oxygen uptake ([VO^2max], e.g., Léger, Mercier, Gadoury, & Lambert, 1988). It characterizes physical activity behavior in children and adults, while norms exist mostly for children above 6 years (Léger, et al., 1988).

low cognitive engagement. In sum, when targeting the effectiveness of an acute physical activity intervention with motor coordination demands for improving executive functions in young children, individual differences in motor coordination experiences have to be considered as a moderator.

2.4.5 Standardized intervention study in the present dissertation

The preceding sections highlight the importance of executive functions in early childhood. One approach for improving executive functions in children is physical activity. Two complementary pathways can explain the effects of physical activity on executive functions and lead to conclusions about effective interventions. A physical activity intervention with moderate-to-vigorous and with motor coordination demands addresses both pathways and thus seems most promising for improving executive functions in children. To date, evidence in young children about the acute effects of physical activity on executive functions is scarce and contradictory. Considering individual differences in motor coordination experiences as moderators may further shed light on the effectiveness of physical activity interventions. Importantly, to derive evidence-based recommendations about the impact of physical activity on executive functions, experimental studies are needed. Consequently, *Manuscript 3* describes a standardized intervention study testing the effectiveness of a physical activity intervention for improving executive functions in young children in a controlled setting.

3 RESEARCH AIMS

This dissertation follows the overarching goal to investigate the potential of physical activity for improving affect and executive functions. Moreover, the possibilities of using ambulatory assessment as a research method in the school context for supporting education are reviewed. The research questions of the three manuscripts shed light on these goals from different perspectives.

Manuscript 1 applies ambulatory assessment to investigate the within-person associations between physical activity and affect in young adults' everyday lives. Affect has been shown to predict health and physical activity has the potential to improve affect. So far, most prior studies refer to between-person comparisons or have methodological limitations. To infer whether naturally occurring physical activity is associated with affect in everyday life, ambulatory assessment studies are indispensable. These results obtained in real life will further enrich physical activity recommendations and support health promotion. In sum, the research questions of *Manuscript 1* are:

(1) How do physical activity and affect fluctuate within-persons from day-to-day?
(2) How are physical activity and affect associated on the within-person level in young adults' everyday lives?
(3) Do the within-person associations between physical activity and affect in young adults' everyday lives change for specific affect states?

Manuscript 2 is a review and describes the use of ambulatory assessment to investigate learning processes in the school context and thereby support education. Prior evidence is often limited to comparisons on the between-person level and lacks ecological validity. Ambulatory assessment is one method extending these shortcomings by offering repeated assessments within-person in real time and real life. The manuscript provides an introduction of ambulatory assessment for researchers and practitioners to support acceptability of ambulatory assessment studies. It highlights the advantages and challenges of applying ambulatory assessment and reviews studies applying ambulatory assessment in schools. The research questions of *Manuscript 2* are:

(1) What is ambulatory assessment and why is its application advantageous in particular in the school context?

(2) How can ambulatory assessment shed light on within-person fluctuations in the school context?
(3) Which challenges have to be faced when applying ambulatory assessment in the school context?

Manuscript 3 describes an intervention study testing the effectiveness of a physical activity intervention for improving executive functions in young children. Given the assumed mechanisms and first empirical findings, physical activity with moderate-to-vigorous intensity and motor coordination demands should be effective for improving executive functions. Moreover, individual differences in motor coordination experiences may moderate the effects. To date, evidence about the effectiveness of physical activity on executive functions in young children (i.e., 4 to 7 years) is scarce. Thus, to infer whether physical activity improves executive functions in young children, intervention studies in controlled settings are needed. These results will further have implications valuable for supporting education. The research questions of *Manuscript 3* are:

(1) Can a physical activity intervention benefit executive functions in young children?
(2) Do children's motor coordination experiences moderate the effectiveness of the physical activity intervention on executive functions?

4 SUMMARY OF MANUSCRIPTS

4.1 Manuscript 1: Physical Activity and Affect in Young Adults' Daily Lives

Haas, P., Schmid, J., Stadler, G., Reuter, M., & Gawrilow, C. (in press). Zooming into daily life: Within-person associations between physical activity and affect in young adults. *Psychology & Health.*

Objective: Negative affect in daily life is linked to poorer mental and physical health. Activity could serve as an effective, low-cost intervention to improve affect. However, few prior studies have assessed physical activity and affect in everyday life, limiting the ecological validity of prior findings. This study investigates whether daily activity is associated with negative and positive evening affect in young adults.

Methods: Young adults (N = 189, Mdn = 23.00) participated in an intensive longitudinal study over 10 consecutive days. Participants wore accelerometers to objectively assess moderate-to-vigorous physical activity continuously throughout the day and reported their affect in time-stamped online evening diaries before going to sleep.

Results: On days when participants engaged in more activity than usual, they reported not only less depressed and angry evening affect but also more vigor and serenity in the evening.

Conclusion: Young adults showed both less negative and more positive affect on days with more activity. Physical activity is a promising health promotion strategy for physical and mental well-being.

4.2 Manuscript 2: Review of Ambulatory Assessment Studies in School

Bugl, P., Schmid, J., & Gawrilow, C. (2015). Ambulantes Assessment in der Schule: Den schulischen Alltag erfahrbar machen [Ambulatory assessment in school: Discovering daily school life]. *Lernen und Lernstörungen, 4*, 261–268. doi:10.1024/2235-0977/a000115

Students' daily lives are characterized by fluctuating learning processes and achievements. Ambulatory assessment can detect these fluctuations within persons. In this way, repeated measurements within short time frames open up a new and valuable perspective on everyday life in schools. The present article aims at introducing ambulatory assessment as a method that enables investigating fluctuations in physiological and mental processes within students and teachers. Importantly, intraindividual changes and fluctuations in behavioral (e.g., physical activity), affective, and cognitive (e.g. executive functions) processes can be detected as they naturally occur within a school day or across days. Thereby, a high ecological validity can be reached and contextual factors of various modalities are assessable. Indeed, preliminary evidence amplifies the meaning and relevance of ambulatory assessed fluctuations in learning-relevant processes for determining academic achievement. For example, ambulatory assessed executive function performance varied significantly within one day among primary school children and could partially be predicted by the quality of last night's sleep (Könen, Dirk, & Schmiedek, 2015). There are many advantages favoring an application directly in the classroom. However, the implementation of an ambulatory assessment study in school remains challenging and demands cooperation between science and practice. Future studies and practical applications are beneficial for all parties involved: students, teachers, parents, and researchers.

4.3 Manuscript 3: Physical Activity Intervention to Improve Young Children's Executive Functions

Haas, P., Cattarius, M., Meibohm, M., Schmid, J., Sudeck, G., Kelava, A., & Gawrilow, C. (2017). Improving young children's executive functions with physical activity: The role of motor coordination experiences. *Manuscript in preparation.*

Objective: Early executive functions are pivotal for future academic and social functioning. Physical activity has been shown to improve executive functions (i.e., cognitive aspects of self-regulation) in adults, while to date the effects in young children are unclear. The present study investigates the effectiveness of acute physical activity to improve subsequent executive functions in young children and also takes the moderating influence of motor coordination experiences into account.

Method: Hundred-three children (46% girls; age: M = 68.50 months, SD = 12.93) were randomly assigned to a physical activity or sitting control condition both conducted in a one-on-one experimenter-child setting. Executive functions were assessed with a behavioural and a computerized task directly following the intervention. Motor coordination experiences, self-control, and sociodemographics of the children were assessed with parental questionnaires.

Results: Performance in both executive function tasks did not differ between children in the physical activity condition compared to the control condition. However, individual differences in children's motor coordination experiences moderated the effectiveness of physical activity: Low levels of motor coordination experiences were linked to negative effects of physical activity on executive functions compared to a sitting activity, whereas a trend indicated positive effects from physical activity on executive functions with higher levels of motor coordination experiences.

Conclusion: Acute physical activity is a promising intervention for improving executive functions in young children when tailored to individual levels of motor coordination experiences. Early support to increase young children's motor coordination experiences may lead to executive function benefits of physical activity for more children.

5 GENERAL DISCUSSION

Physical inactivity in adults and children is a widespread phenomenon in the Western world (Troiano et al., 2008) and one of the leading risk factors of mortality nowadays (WHO, 2014). In the same vein, physical activity has multiple positive effects, as for instance to benefit mental health (Deslandes et al., 2009). In this way, engaging in physical activity seems promising for improving well-being and cognitive functioning. However, prior studies on the potential of physical activity ignore important aspects, such as the transfer of effects into everyday life and to specific age groups.

Given the theoretical and empirical background the present dissertation addresses existing gaps in the literature and aims at deriving implications for health promotion and for supporting education. More precisely, the present dissertation investigates the potential of physical activity for improving well-being and cognitive functioning by relying on ambulatory assessment and intervention methods. *Manuscript 1* sheds light on the potential of physical activity to improve affect in young adults' daily lives in an ambulatory assessment study. *Manuscript 2* reviews the advantages of applying ambulatory assessment in school and for supporting educational success. *Manuscript 3* elucidates the potential of physical activity to improve executive functions in young children in a standardized intervention study.

This chapter concludes with a general discussion of the findings obtained in the present dissertation. In Section 5.1 the main findings of the three manuscripts are summarized and discussed, followed by an outline of the limitations and directions for future research in Section 5.2. Section 5.3 presents the strengths of the present dissertation and Section 5.4 summarizes the practical implications. Finally, Section 5.5 ends with general conclusions.

5.1 Summary and Discussion of Main Results

The present dissertation aimed at investigating the potential of physical activity for improving well-being and cognitive functioning by relying on ambulatory assessment and intervention methods and thereby to derive implications for health and education. Its *main results* are the following: (a) physical activity has the potential to improve affect in young adults, as shown by within-person-associations between

physical activity and improved affect in young adults' daily lives (*Manuscript 1*), (b) applying ambulatory assessment in the school context is advantageous for supporting educational success, as shown by a review of ambulatory assessment studies (*Manuscript 2*), and (c) physical activity has the potential to improve executive functions in young children with high levels of motor coordination experiences, as shown by a moderating effect of children's prior motor coordination experiences on the effectiveness of a physical activity intervention on executive functions in young children (*Manuscript 3*). In the following, the research aims of the present dissertation raised in Chapter 3 will be answered more precisely. The main results of the three manuscripts that constitute the present dissertation will be summarized and discussed.

The potential of physical activity for improving affect was investigated in young adults' daily lives in *Manuscript 1*. We applied ambulatory assessment in an intensive longitudinal study across 10 consecutive days in 189 young adults. Moderate-to-vigorous physical activity (from now on referred to as *physical activity*) was assessed objectively and specific positive and negative affect states were reported in daily online evening diaries. The main results of this study are that (a) fluctuations of physical activity and affect are observable and reliably measurable within-persons from day-to-day, (b) within-person associations between physical activity and affect exist in young adults' everyday lives, and (c) these within-person associations differ for specific affect states. To be more precise on the latter findings, we found significant within-person associations between objectively assessed physical activity and improved evening affect. On days with more physical activity than usual, participants reported less depressed and less angry affect in the evening, but not less anxious affect. In addition, on days with more physical activity than usual, participants reported more vigor and more serenity, but also more fatigue. However, participants engaging in more physical activity than others reported less fatigue. Taken together, these results demonstrate that more physical activity than usual is associated with specific affect states pertaining to all four combinations of valence and activation (see Section 2.3.1).

Our finding of an association between more physical activity than usual and less negative affect (i.e., depression, anger) corroborates previous results of cross-sectional, longitudinal and intervention studies (Conn, 2010; Mammen & Faulkner, 2013; Parfitt, Rose, & Markland, 2000; Poole et al., 2011; Puetz, O'Connor, & Dishman, 2006; Rimer et al., 2012) and provides further evidence of the potential of naturally occurring physical activity for affect in real life given the mixed findings of the few within-person

studies available (Liao et al., 2015). The small size of our within-person effects can be attributed to the seldom experience of the rather intense items pertaining to the negative affect scales (e.g., *hopeless*) in our sample of healthy adults. However, our significant findings suggest that even naturally occurring physical activity throughout the day, including unstructured physical activity as well as exercise, is associated with less negative evening affect. In the long term, it is conceivable that these small effects may accumulate into a generally enhanced state of well-being and serve as effective health prevention against the negative consequences of repeatedly experiencing negative affect.

In addition, our finding of an association between more physical activity than usual and more positive affect (i.e., vigor, serenity) is in line with prior within-person studies (Fortier, Guerin, Williams, & Strachan, 2015; Hyde, Conroy, Pincus, & Ram, 2011; Kanning, 2013; Kanning & Schlicht, 2010; Maher et al., 2013; Mata et al., 2012; Schwerdtfeger et al., 2008; Wichers et al., 2012). However, the present study differs systematically from prior studies in (a) assessing affect more distally (i.e., at the end of day) and in (b) differentiating between varying activation levels of positive affect (i.e., pleasant-activated: vigor vs. pleasant-deactivated: serenity). Consequently, these study results extend previous findings and further contribute to confirm the association between physical activity and positive affect in young adults' daily lives.

The findings for fatigue impressively illustrate how results can differ on the within-person and between-person level. In contrast to the few existing within-person studies (e.g., Kanning, 2013), we found that more physical activity than usual is associated with more fatigue in the evening. This increased level of evening fatigue can be considered as a positive effect of activity as it may benefit sleep quality (Kredlow, Capozzoli, Hearon, Calkins, & Otto, 2015). When taking the between-person perspective, participants with more physical activity than others reported less fatigue in the evening. Possibly, these participants engage more regularly in physical activity and have higher fitness levels resulting in less overall fatigue, as shown in intervention studies (Puetz et al., 2006).

Manuscript 2 provided a comprehensive introduction of ambulatory assessment with the focus of applying it in school to support educational success. Besides, the advantages of ambulatory assessment were exemplified with a review of prior ambulatory assessment studies in schools. The main results of this manuscript are trifold. First, (a) the application of ambulatory assessment in the school context is

advantageous in order to investigate within-person fluctuations of students and teachers in the school context with regard to various domains, such as behavioral (e.g., physical activity), affective, and cognitive (e.g. executive functions) processes. Consequently, the influences on learning processes can be discovered from a multi-method and multi-informant perspective. Ambulatory assessment can identify antecedents, consequences and correlates of learning processes and these results broaden our understanding of academic achievement. In the long term, ambulatory assessment provides evidence relevant for supporting educational success. Second, (b) ambulatory assessment can be implemented in the regular school day as the assessments can take place with mobile devices and do not require a laboratory setting (e.g., as in Könen et al., 2015). Third, (c) to successfully apply ambulatory assessment in the school context the manuscript also outlines important challenges that have to be met, as for instance to have sufficient methodological skills and to guarantee ethical principles and data protection (Miller, 2012). In sum, this manuscript resulted in amplifying the advantages of applying ambulatory assessment in school for researchers and practitioners. The manuscript, thus, aims at encouraging future ambulatory assessments studies.

Manuscript 3 investigated the potential of physical activity to improve executive functions in young children aged 4 to 7 years in a standardized intervention study. Following a stratified randomization plan controlling for age and gender, 51 children were assigned to a physical activity intervention with moderate-to-vigorous intensity and motor coordination demands, and 52 children were assigned to a sitting control condition listening to a story. Directly following the intervention or control condition, executive functions were assessed by a behavioral and a computerized task. The main results of this study are that (a) children in the intervention condition did not perform better in both executive function tasks than children in the control condition and that (b) children with higher levels of motor coordination experiences seemed to perform better in the behavioral executive function task when having participated in the intervention compared to the control condition than children with lower levels of motor coordination experiences. No moderating effect of motor coordination experience was present with regard to children's performances in the computerized executive function task.

The missing effect of physical activity on executive functions in the present study is in line with some studies in children (Cooper, Bandelow, Nute, Morris, & Nevill, 2012; Jäger et al., 2015; Mierau et al., 2014; Palmer et al., 2013; Pirrie & Lodewyk, 2012; Stein, 2016), but stands in contrast to other studies (Best, 2012;

Ellemberg & St-Louis-Deschênes, 2010; Hillman et al., 2009; Jäger et al., 2014; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). Multiple alternative explanations have been ruled out. In this way, the missing effect of physical activity compared to a sitting activity on executive functions in the present study cannot be attributed to (a) pre-existing differences of children in the intervention and control condition, such as differences in age, gender or self-control, (b) affective or motivational differences between the conditions, nor to (c) low sensitivity of executive functions tasks, as observable in ceiling or floor effects. Consequently, further explanations for this null finding could be due to (d) the content of the physical activity intervention, and (e) differential effects for young children.

First, (d) the content of our physical activity intervention with motor coordination demands and moderate-to-vigorous intensity was in line with theoretical considerations of addressing both the learning and physiological pathway that mediate the effects of physical activity on executive functions (Sibley & Etnier, 2003; see Section 2.4.3). However, we chose one medium level of motor coordination demands that may have been too narrow to be effective for all children with varying levels of motor coordination experiences. In line with this argument, positive effects of physical activity with motor coordination demands have been found in elite sport students that represent a homogenous sample with respect to their motor coordination skills (Budde et al., 2008). In addition, we chose a physical activity intervention with moderate-to-vigorous intensity as evidenced by objective recordings of children's heart rates and in line with prior findings of beneficial activity effects on executive functions (e.g., Hillman et al., 2009). However, in contrast to the lab-based physical activities with steady intensity (as for instance when cycling on an ergometer; Hillman et al., 2009), in the present intervention heart rates fluctuated considerably from minute-to-minute. Whether the nature of intensity differentially affects executive functions has to be investigated in future projects. Second, (e) the missing effect of physical activity on executive functions could be due to specific characteristics of young children. Prior results are mainly based on children aged above 7 years and adults and it remains questionable whether a direct generalization to young children is possible. It could be that due the different type of physical activity behavior in (de Bock et al., 2010) or due to the early developmental level of executive functions other mechanisms, underlying the benefits of physical activity on executive functions, are in place in young children compared to the mechanisms working in older children or adults.

Moreover, we found that children's individual differences in prior motor coordination experiences moderated the physical activity effects on executive functions. In line with the notion of an *optimal challenge point* where the demands of physical activity match with the individual's ability level (Pesce, 2009), benefits of physical activity on executive functions were only present in children with higher levels of motor coordination experiences (for an extended discussion, see *Manuscript 3*). Thus, tailoring the content of physical activity interventions to children's individual level of motor coordination experiences seems crucial to derive effects from physical activity on executive functions in young children.

5.2 Limitations and Directions for Future Research

The present dissertation is not without limitations. Nevertheless, it lays the pavement for future research in the area of physical activity and affect as well as executive functions. In addition, it highlights the benefits of applying ambulatory assessment in the school context. Three *main limitations* can be identified. First, demonstrating a causal link between physical activity and affect was beyond the scope of the study in *Manuscript 1*, but should be addressed in future studies to corroborate practical applications. Second, investigating the mechanisms underlying the potential of physical activity for improving well-being and cognitive functioning extends the focus of *Manuscript 1* and *3*, but is indispensable for an in-depth understanding of physical activity effects and should thus be investigated in the future. Third, ambulatory assessment has been applied in the present study, but further applications especially in the school context seem highly promising to support educational success (*Manuscript 2*). In the following, the main limitations and future directions derived from each manuscript will be specified.

Manuscript 1 has the following limitations. First, a causal effect of physical activity on affect cannot be inferred from the present findings. However, we have confirmed a temporal order with the finding that daytime physical activity is associated with evening affect. Moreover, our ambulatory assessment study allowed ruling out individual differences as alternative explanations for the activity-affect association within-persons. Future studies could address causality by implementing a more structured assessment strategy of ambulatory assessment (see Section 2.2.1). Device-contingent monitoring can be used to provide further hints for causality of naturally

occurring physical activity and affect, as in this case real-time recordings of predefined physical activity levels trigger affect assessments. However, to establish causality and therefore to rule out time-varying alternative explanations of the within-person activity-affect association, intervention studies are indispensable, where physical activity is experimentally increased, for instance, on specific days.

Second, the mechanisms underlying the association between physical activity and affect were beyond the scope of the present study and need to be investigated in future projects. To date, multiple mechanisms derived from human and animal experiments are discussed (for an overview: Lehnert et al., 2012), as for instance psychological processes (e.g., higher self-efficacy and self-esteem; Spence et al., 2005), as well as physiological processes (e.g., favorable hormonal and neurotransmitter changes; Biddle & Mutrie, 2008, p.280; see Section 2.3.3). However, conclusive evidence demonstrating how these mechanisms work together and in real life is missing, so far. Future intervention studies can address these unsolved questions. Further on, first hints of causality can also be derived from ambulatory assessment studies that additionally assess time-varying mechanisms in daily life, such as self-esteem or serotonin synthesis (Biddle & Mutrie, 2008). Moreover, claims about a bidirectional association between physical activity and affect have been raised in the way that also improved affect predicts increased levels of physical activity (e.g., Schwerdtfeger, Eberhardt, Chmitorz, & Schaller, 2010). This has not been addressed in the present study, so far. To account for dynamic temporal patterns and bidirectionality (e.g., as in time-series models; Brandt & Williams, 2007), future studies with higher sampling frequency are needed (e.g., Stavrakakis et al., 2015). In addition, given the mixed effects found in prior studies (Liao et al., 2015), one direction of future research is to focus on between-person differences in within-person associations. It is possible that individuals with dispositionally higher negative affect may benefit more from physical activity than individuals with dispositionally lower negative affect, as they have more room for improvement. Ambulatory assessment studies with large sample sizes and high frequency sampling can serve to elucidate potential moderator effects.

Third, the influence of quantitative and qualitative aspects of physical activity (see Section 2.1.1) on affect in everyday life remains mostly unclear. In this way, future studies should focus on the dose-response relationship to corroborate the present finding that increasing the daily amount of moderate-to-vigorous physical activity goes along with improved affect. Besides, some studies point towards context-specific effects of

physical activity on affect, such as increased benefits of physical activity in the presence of others than alone (Dunton et al., 2015) or during leisure as compared to non-leisure time (Kanning, 2013) or outdoors as compared to indoors (Focht, 2009). These factors should be investigated in future studies, while always considering participants' study burden. Further limitations are discussed in *Manuscript 1*.

Manuscript 2 also has some limitations leading to future research ideas. First, this review aims at outlining important arguments that may support acceptability and feasibility of ambulatory assessment in schools. However, this is just a first step. Future studies in schools may investigate how parents, teachers and school directors can most effectively be convinced about the advantages of ambulatory assessment research. Importantly, ambulatory assessment studies are demanding for participating students and teachers, while the participant burden should be as low as possible to answer the research questions. Thus, further dialogues between research and school agents are necessary for paving the ground of ambulatory assessment studies. One further step to facilitate ambulatory assessment research in school could be to develop an infrastructure, for instance with a protocol accepted by research and school agents that specifies ethical principles and data protection during sampling, storage and analysis. Second, despite the manifold advantages of applying ambulatory assessment in schools, future research is indispensable before ambulatory assessment can be used as a diagnostic tool or intervention in the regular school practice. Future studies testing the effectiveness of evidence-based interventions in daily school life are valuable to derive evidence for practical implications. One exemplary intervention, usable in ambulatory assessment studies, is a recently developed mobile application for adults that implements evidence-based strategies to increase self-regulation in everyday life (application WOOP: Wish-Outcome-Obstacle-Plan, http://woopmylife.org; evidence: Gawrilow, Morgenroth, Schultz, Oettingen, & Gollwitzer, 2013). Moreover, the study described in *Manuscript 3* of the present dissertation also provides first evidence on the effectiveness of a specific intervention for improving executive functions when tailored to the level of motor coordination experiences of young children. Future ambulatory assessment studies implementing this intervention in the regular school or kindergarten day can further contribute to derive evidence for large-scale applications in the practice.

Manuscript 3 has the following limitations. First, the present study provides first hints that children's level of prior motor coordination experiences is crucial for benefits of physical activity on executive functions. However, future intervention studies should

directly manipulate children's level of motor coordination experiences to corroborate the present finding and to identify an absolute level of motor coordination experiences needed for physical activity benefits on executive functions in young children. Second, we found the moderation effect only for the behavioral executive function task, but not for the computerized task. Thus, it could be interesting to disentangle whether this effect is attributable to the executive or motor demands of the present behavioral executive function task (i.e., Head-Toes-Knees-shoulder task). In this vein, further experimental studies could implement some modified trials within the task that only target motor demands. This could rule out the alternative explanations that physical activity benefits solely motor demands. Third, assessing the mechanisms underlying the physical activity effects on executive functions were beyond the scope of the present study. Although the content of our physical activity intervention (i.e., moderate-to-vigorous intensity, moderately high motor coordination demands) was chosen in line with theoretical and empirical notions on two underlying processes mediating the effects of physical activity on executive functions (Sibley & Etnier, 2003), we did not directly test whether our physical activity intervention actually influenced physiological and learning processes. Certainly, the present study extends most prior studies by measuring children's heart rate objectively during the physical activity intervention and thus providing a sophisticated manipulation check. However, specific physiological mechanisms have not been addressed. Future research should corroborate the assumed mechanisms in young children. Physiological processes could, for instance, be investigated by measuring the prefrontal cerebral blood flow with mobile technologies, such as near-infrared spectroscopy. Fourth, we assumed that our physical activity intervention addresses both physiological and learning processes simultaneously and that this will result in additive effects. However, further experimental studies should explicitly manipulate the degree of which both processes are addressed, by varying, for instance, the intensity level or the level of motor coordination demands to elucidate the effects of isolated elements of physical activity interventions. Fifth, assessing the sustainability of acute physical activity effects on executive functions was beyond the scope of the present study. Future research should focus on the durability of acute physical activity benefits on executive functions. One study in children (aged 6 to 8 years) showed that physical activity benefits executive functions immediately and up to 20 minutes, but no effects were found 40 minutes after physical activity (Jäger et al., 2014). In this way, future intervention studies may implement additional testing sessions in fixed time

frames. Sixth, we relied on a parent questionnaire for assessing children's motor coordination experiences. Future studies may corroborate our findings by assessing motor coordination more objectively using standardized behavioral tests (e.g., Petermann, 2008). Further limitations are discussed in *Manuscript 3*.

5.3 Strengths

The strength of the present dissertation lies in its contribution to the current evidence base on the potential of physical activity for improving affect and executive functions. Moreover, two unique characteristics mark the *main strength* of the present dissertation. First, we applied highly advantageous and sophisticated methods, such as ambulatory assessment and standardized intervention studies. Second, we targeted specific samples, such as young adults and young children, who benefit in particular from physical activity. In the following, the strengths of each manuscript will be specified.

Manuscript 1 makes several important contributions. First, this study in everyday life with a young adult sample is among the first to demonstrate that days with more physical activity than usual were associated with less negative evening affect and more positive evening affect. Consequently, it makes an important contribution to the limited evidence available on the topic of within-person associations between naturally occurring physical activity and affect in real life (Liao et al., 2015). Moreover, the present study is of practical relevance as we targeted young adults who are especially at risk for low positive and high negative affect (Carstensen et al., 2011) that in turn often imply negative consequences for physical and mental health (e.g., Kiecolt-Glaser, McGuire, Robles, & Glaser, 2002). Second, we chose a measure of affect that has been shown to reliably capture within-person changes (Cranford et al., 2006) and also demonstrated adequate within-person reliability in the present study. In addition, by assessing specific affect states according to the approach of distinct affect states (negative vs. positive valence × high vs. low activation), the present study could disentangle how physical activity is associated with specific affect states, such as the fact that more physical activity than usual is not only linked to less negative affect in general, but more precisely to less depression (i.e., unpleasant-deactivated) and less anger (i.e., unpleasant-activated). This extends results from prior within-person studies and offers high practical relevance as strategies for affect management are inferable.

Third, we assessed physical activity objectively with accelerometers that represent the gold standard of physical activity assessment in daily life (Trull & Ebner-Priemer, 2013) and avoid short-comings of self-reports (Prince et al., 2008). In addition, we assessed naturally occurring physical activity across 10 consecutive days and thereby reached a high level of ecological validity. Prior intervention studies implemented physical activity in form of instructed exercise. However, our findings demonstrate that also spontaneous unstructured physical activity, that is naturally incorporated in young adults' daily lives, such as walking to commute, contributes to the association between physical activity and enhanced affect. Fourth, we assessed daily evening affect via time-stamped online diaries that allowed us to control for invalid entries that are non-conform to the study protocol and thus ensures internal validity. Fifth, unlike most prior within-person studies we captured within-person associations on a daily level that allow enriching existing national and international physical activity recommendations, as these also refer to daily levels of physical activity (American Heart Association, 2016; European Working Group, 2008), and are thus highly relevant for practical applications.

The strengths of *Manuscript 2* are directly related to the advantages of applying ambulatory assessment in schools. First, ambulatory assessment focuses on within-person changes and thus acknowledges in particular the individuality of each student, as for instance by referring to individual reference norms, such as previous academic achievements, and not to social reference norms, such as comparisons of academic achievements among students (Rheinberg, 1983). Individual reference norms are especially useful to support the development of high and low achieving students. Second, evidence from ambulatory assessment research in schools fosters theory development about learning processes and academic achievement, as for instance by identifying optimal learning conditions. Third, ambulatory assessment fosters the use of advanced technologies, such as smartphones or physiological monitors, in psychological research. Thereby, psychological research benefits from the multiple advantages of these technologies, as for instance time-stamped assessments or mobile assessments in everyday life settings.

Manuscript 3 boasts several strengths. First, to our knowledge this is the first standardized intervention study investigating the effects of physical activity on subsequent executive functions in a sample of young children aged 4 to 7 years. The results provide first hints for closing this gap in the literature and highlight important aspects that need to be considered in future studies, such as individual differences in

motor coordination experiences. Second, the present study had a one-on-one experimenter-child setting that was highly standardized but still child-oriented and thus provides high internal validity. This study characteristic extends many prior studies in children that were conducted in the field where social influences (e.g., due to group settings) are present and physical activity engagement cannot be strictly supervised. Third, the present study included comprehensive manipulation checks as compared to most prior studies, as for instance objective recordings of children's heart rate during the intervention and control condition, and children's reports on affect and enjoyment of the condition. This allowed ruling out multiple confounders. Fourth, we controlled for important background characteristics that influence executive functions, such as children's self-control, age, and gender. Fifth, we developed an intervention based on theoretical considerations of the underlying mechanisms and adapted it to be close to natural forms of physical activity in young children (de Bock et al., 2010). Its moderate-to-vigorous intensity has been evidenced by objective measures and its motor coordination demands were rated by experts. Thus, the present intervention consists of the most promising elements for improving executive functions and is usable in future studies.

5.4 Practical Implications

The present dissertation allows drawing important implications for mental health and education that will be summarized and illustrated in the following. First, physical activity may serve as health promotion strategy in young adults as we have shown that more physical activity than usual is linked with improved evening affect (*Manuscript 1*) and given prior causal evidence from intervention studies (Rethorst et al., 2009). Our results imply that increasing the daily amount of moderate-to-vigorous physical activity can serve as an effective tool for managing anger and depressed affect as well as for supporting vigor and serenity. This means that physical activity can influence specific affect states of all four combinations of valence and activation. Thus, meeting daily physical activity recommendations supports not only physical health, but also mental health. Programs targeting young adults seem highly promising as this age group experiences lower affect than older adults (Carstensen et al., 2011) and in light of the high prevalence of physical inactivity (Lampert, Mensink, & Muters, 2012; Troiano et al., 2008). To increase physical activity in young adults' everyday lives, it seems

promising to not only support regular participation in exercise programs but also to encourage young adults to increase the amount of unstructured physical activity, such as walking or bicycling to commute or to buy groceries. Since engagement in unstructured physical activity is not fixed to scheduled times or specific places, unstructured physical activity has the advantage of being more feasible and more easily to integrate into daily life than exercise sessions. Importantly, even when individuals have the intention to be more physically active they often do not change their actual behavior (Rhodes & Bruijn, 2013). To bridge this intention-behavior gap, action planning (Sniehotta, Scholz, & Schwarzer, 2005) and self-regulation strategies (e.g., implementation intentions; Stadler, Oettingen, & Gollwitzer, 2009; monitoring and feedback; Prestwich, Conner, Hurling, Ayres, & Morris, 2016) supported by mobile devices, such as fitness trackers or applications for smartphones, can serve as useful tools and can additionally be tailored to individual needs. In sum, health promotion in young adults should aim at increasing physical activity for maintaining and promoting mental health and can make use of already established intervention strategies.

Second, the review of ambulatory assessment studies in schools demonstrates the importance of taking short-term fluctuations in learning processes into account (*Manuscript 2*). Consequently, ambulatory assessment fosters to adopt an idiosyncratic perspective in the way that, for instance, performances in exams are evaluated as momentary learning states and with reference to prior performances within students (i.e., individual reference norm; Rheinberg, 1983). Fluctuations in learning processes within students could be easily displayed by the time course of exam performances of one student resultant from ambulatory assessment. This individual time course may represent an ideal starting point for consultations with students, parents and teachers in the case of learning problems. In addition, to focus on the individual time course of performances assessed in the regular school context in the case of learning problems provides highly valuable information and adds up to the results obtained in the usually conducted single-session tests outside the classroom.

Third, physical activity can be used as an effective intervention for improving executive functions of young children with high levels of motor coordination experiences in the short term (*Manuscript 3*). Targeting in particular young children seems promising since executive functions pave the ground for future social and academic functioning (Ursache et al., 2012) and since they undergo important developments during this age period (Garon et al., 2008). To yield effects on executive

functions, physical activity interventions should not only include moderate-to-vigorous intensity and motor coordination demands but also be tailored to the individual level of motor coordination experiences of the participating children. Short questionnaires or tests (e.g., Bayer, Jarczok, Fischer, Kries, & Bock, 2012; Petermann, 2008) can help to identify children's level of motor coordination. Moreover, the family context as well as educational institutions offer great possibilities to regularly and systematically promote children's motor coordination experiences. Thus, informing and encouraging parents to foster motor coordination experiences in their children, as for instance by integrating physical activity games before dinner or regular trips to the local swimming pool into daily family routine, seems highly promising. In addition, national curricula of early education already emphasize that educational institutions are obliged to support children's engagement in physical activity with a wide diversity of motor coordination demands (e.g., KM BW, 2011). In this way, educators are sensitized to promote children's motor coordination development and many kindergartens have special activity rooms that offer ideal conditions for children to experience diverse motor coordination demands. Besides, cooperations between kindergartens and local sports club can facilitate children's access to motor coordination experiences, as for instance by offering sports club activities in the kindergarten. The present study further gives scientific proof for the benefits of promoting motor coordination experiences in children (Roth et al., 2010). If more children have access to motor coordination experiences on a regular basis, physical activity interventions may lead to improved executive functions in the majority of these children.

5.5 Conclusions

The present dissertation shows that physical activity has the potential of improving affect in young adults and executive functions in young children depending on their motor coordination experiences. Thus, physical activity has not only the potential of *adding years to life* in terms of improved physical health shown in prior studies, but also of *adding life to years* with respect to enhanced affect and executive functions and thus, improved mental health (cf. Biddle & Mutrie, 2008, p.13). Further on, ambulatory assessment has been identified as an advantageous research approach in the school context and in young adults' daily lives. Importantly, the present dissertation

allows a transfer of effects into everyday life and to specific age groups and thereby fills the gaps resultant from prior studies.

With respect to the high prevalence rate of physical inactivity, the present dissertation supports the notion, that attempts of systematically increasing physical activity across age groups are worthwhile to yield effects on mental health. With these results on how to use physical activity to derive benefits for mental health, the present dissertation makes important contributions for supporting health promotion and educational success.

GERMAN SUMMARY

Bewegungsmangel ist ein weit verbreitetes Phänomen in der westlichen Welt. Er wirkt sich negativ auf die Gesundheit aus und stellt den vierthäufigsten Risikofaktor globaler Mortalität dar. Bewegung oder körperliche Aktivität ist ein effektives Werkzeug zur Verbesserung der physischen Gesundheit und kann zudem auch zur Verbesserung der psychischen Gesundheit dienen. Die vorliegende Dissertation zielt darauf ab, die potenziellen Vorteile körperlicher Aktivität für den Affekt und die exekutiven Funktionen, die beide Aspekte psychischer Gesundheit darstellen, zu untersuchen. Es werden insbesondere drei spezifische Forschungsziele verfolgt. Zum einen soll durch Anwendung ambulanten Assessments der Zusammenhang zwischen körperlicher Aktivität und dem Affekt im Alltag junger Erwachsener untersucht werden (*Manuskript 1*). Darüber hinaus werden die Anwendung ambulanten Assessments im Schulkontext, das die Erfassung von körperlicher Aktivität, Affekt und exekutiven Funktionen mit einschließt, sowie ihre Vorteile zur Förderung des Bildungserfolgs überblicksartig zusammengefasst (*Manuskript 2*). Zudem wird die Effektivität einer Bewegungsintervention zur Verbesserung der exekutiven Funktionen von jungen Kindern in einer standardisierten Interventionsstudie untersucht (*Manuskript 3*). Durch dieses Vorgehen erweitert und bereichert die vorliegende Dissertation theoretische und empirische Erkenntnisse auf zwei Arten. Zum einen nimmt sie insbesondere den Transfer von Effekten ins tägliche Leben in den Fokus durch die Anwendung ambulanten Assessments. Zum anderen zielt sie auf spezifische Altersgruppen ab, junge Erwachsene und junge Kinder, die besonders empfänglich für die Vorteile körperlicher Aktivität zu sein scheinen, da der Affekt junger Erwachsener besonders niedrig ist und sich die exekutiven Funktionen junger Kinder in der Entwicklung befinden.

Manuskript 1 untersuchte die Zusammenhänge zwischen körperlicher Aktivität und dem Affekt im Alltag junger Erwachsener. Ambulantes Assessment wurde in einer intensiven Längsschnittstudie mit 189 jungen Erwachsenen über 10 konsekutive Tage angewendet. Die Teilnehmer trugen einen Beschleunigungsmesser zur objektiven und kontinuierlichen Erfassung moderater bis anstrengender körperlicher Aktivität über den Tag hinweg und berichteten ihren Affekt vor dem Zubettgehen in Online-Abendtagebüchern mit Zeitstempel. Mehrebenenanalysen ergaben signifikante Zusammenhänge zwischen der körperlichen Aktivität am Tag und dem Affekt am Abend desselben Tages innerhalb von Personen. An Tagen, an denen die Teilnehmer

körperlich aktiver waren als für sie üblich, berichteten sie nicht nur einen geringeren depressiven Affekt und weniger Ärger am Abend, sondern auch mehr Energie und Gelassenheit. Diese Ergebnisse erweitern vorherige Befunde durch die Evidenz aus dem Alltag und durch den Fokus auf Zusammenhänge zwischen körperlicher Aktivität und spezifischen Affektzuständen. Darüber hinaus erlauben die Ergebnisse, praktische Implikationen für Gesundheitsförderprogramme für junge Erwachsene abzuleiten.

Manuskript 2 gab einen Literaturüberblick über die Anwendung ambulanten Assessments im Schulkontext. Es bot eine Einführung zum ambulanten Assessment als eine Methode, die die Untersuchung von Schwankungen physiologischer und mentaler Prozesse innerhalb von Schülerinnen und Schülern sowie Lehrkräften ermöglicht. Genau genommen können intraindividuelle Veränderungen und Schwankungen in behavioralen (z.B. körperliche Aktivität), affektiven und kognitiven (z.B. exekutive Funktionen) Prozessen entdeckt werden, so wie sie natürlicherweise innerhalb eines Schultages oder über Tage hinweg auftreten. Dadurch kann eine hohe ökologische Validität erreicht werden und Kontextfaktoren verschiedenster Modalitäten sind erfassbar. Darüber hinaus können die Ergebnisse ambulanter Assessmentstudien in der Schule die Grundlage für Theorieentwicklungen zur Ätiologie von Schulleistungen darstellen. Folglich hebt dieses Manuskript die Vorteile der Anwendung ambulanten Assessments in der Schule zur Unterstützung des Bildungserfolgs hervor.

Manuskript 3 beschrieb eine standardisierte Interventionsstudie, an der 103 junge Kindern teilnahmen. Die Studie untersuchte die Effektivität akuter körperlicher Aktivität zur Verbesserung der exekutiven Funktionen und berücksichtigte zudem den moderierenden Einfluss von früheren motorisch-koordinativen Erfahrungen. Die Kinder wurden randomisiert einer körperlichen Aktivitäts- oder sitzenden Kontrollbedingung zugewiesen, die beide in einem 1:1 Versuchsleiter-Kind-Setting durchgeführt wurden. Die exekutiven Funktionen wurden mit zwei Aufgaben direkt nach den Interventionen erfasst. Die motorisch-koordinativen Erfahrungen wurden anhand eines Elternfragebogens gemessen. Regressionsanalysen zeigten keinen Unterschied in beiden exekutiven Funktionsaufgaben zwischen Kindern in der körperlichen Aktivitäts- und der Kontrollbedingung. Allerdings moderierten individuelle Unterschiede in den motorisch-koordinativen Erfahrungen der Kinder die Effektivität körperlicher Aktivität für die Verbesserung der exekutiven Funktionen. Für Kinder mit niedrigerem Niveau motorisch-koordinativer Erfahrungen ergaben sich negative Effekte von körperlicher Aktivität auf die exekutiven Funktionen im Vergleich zur sitzenden Aktivität,

wohingegen für Kinder mit höherem Niveau motorisch-koordinativer Erfahrungen ein Trend positive Effekte körperlicher Aktivität auf die exekutiven Funktionen andeutete. Diese Ergebnisse ermöglichen es, kausale Inferenzen über die Effekte körperlicher Aktivität auf die exekutiven Funktionen abzuleiten und erweitern vorherige Befunde durch die Anwendung standardisierter Methoden bei jungen Kindern. Außerdem können praktische Implikationen für den Einsatz körperlicher Aktivität in der frühkindlichen Bildung abgeleitet werden.

Insgesamt zeigt die vorliegende Dissertation, dass körperliche Aktivität als Werkzeug zur Verbesserung des Affekts bei jungen Erwachsenen und der exekutiven Funktionen bei jungen Kindern dienen kann und demnach zur Verbesserung psychischer Gesundheit. Darüber hinaus unterstreicht sie den Wert der Anwendung ambulanten Assessments, um Evidenz im Alltagsleben zu erhalten, und insbesondere der Anwendung im Schulkontext zur Bildungsförderung. Folglich erbringt die vorliegende Dissertation konzeptuelle Erkenntnisse über die Potenziale körperlicher Aktivität zur Verbesserung des Affekts und der exekutiven Funktionen. Es werden praktische Implikationen für den Nutzen körperlicher Aktivität zur Gesundheits- und Bildungsförderung, sowie mögliche Wege zukünftiger Forschungsarbeiten diskutiert.

REFERENCES

ActiGraph. (2013). ActiGraph GT3X+ and wGT3X+ Device Manual. Pensacola (FL).

Ainsworth, B. E., Haskell, W. L., Leon, A. S., Jacobs, D. R., Montoye, H. J., Sallis, J. F., & Paffenbarger, R. S. (1993). Compendium of physical activities: Classification of energy costs of human physical activities. *Medicine and Science in Sports and Exercise, 25*, 71–80.

Allan, N. P., Hume, L. E., Allan, D. M., Farrington, A. L., & Lonigan, C. J. (2014). Relations between inhibitory control and the development of academic skills in preschool and kindergarten: A meta-analysis. *Developmental Psychology, 50*, 2368–2379. doi:10.1037/a0037493

Allport, G. W. (1942). *The use of personal documents in psychological science*. New York: Social Science Research Council.

American Heart Association. (2016). *Recommendations for physical activity in adults.* Retrieved from http://www.heart.org/HEARTORG/HealthyLiving/PhysicalActivity/FitnessBasics/American-Heart-Association-Recommendations-for-Physical-Activity-in-Adults_UCM_307976_Article.jsp

Barenberg, J., Berse, T., & Dutke, S. (2011). Executive functions in learning processes: Do they benefit from physical activity? *Educational Research Review, 6*, 208–222. doi:10.1016/j.edurev.2011.04.002

Barta, W. D., Tennen, H., & Litt, M. D. (2012). Measurement reactivity in diary research. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 108–123). New York: Guilford Press.

Bayer, O., Jarczok, M., Fischer, J., Kries, R. von, & Bock, F. de. (2012). Validation and extension of a simple questionnaire to assess physical activity in pre-school children. *Public Health Nutrition, 15*, 1611–1619. doi:10.1017/S1368980012001243

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review, 30*, 331–351. doi:10.1016/j.dr.2010.08.001

Best, J. R. (2012). Exergaming immediately enhances children's executive function. *Developmental Psychology, 48*, 1501–1510. doi:10.1037/a0026648

Biddle, S., & Mutrie, N. (2008). *Psychology of physical activity: Determinants, well-being and interventions* (2nd ed.). London: Routledge.

Blair, C. (2002). School readiness: Integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. *American Psychologist, 57,* 111–127. doi:10.1037//0003-066X.57.2.111

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development, 78,* 647–663. doi:10.1111/j.1467-8624.2007.01019.x

Blair, C., & Ursache, A. (2011). A bidirectional model of executive functions and self-regulation. In R. F. Baumeister & K. D. Vohs (Eds.), *Handbook of self-regulation: Research, theory and applications* (2nd ed., pp. 300–320). New York: Guilford Press.

Bolger, N., & Laurenceau, J.-P. (2013). *Intensive longitudinal methods: An introduction to diary and experience sampling research*. New York, London: Guilford Press.

Brandt, P. T., & Williams, J. T. (2007). *Multiple time series models*. *Quantitative applications in the social sciences: Vol. 148*. Thousand Oaks: Sage Publications.

Brose, A., Voelkle, M. C., Lövdén, M., Lindenberger, U., & Schmiedek, F. (2014). Differences in the between-person and within-person structures of affect are a matter of degree. *European Journal of Personality, 29,* 55–71. doi:10.1002/per.1961

Bryk, A. S., & Raudenbush, S. W. (1987). Application of hierarchical linear models to assessing change. *Psychological Bulletin, 101,* 147–158. doi:10.1037/0033-2909.101.1.147

Budde, H., Voelcker-Rehage, C., Pietraßyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441,* 219–223. doi:10.1016/j.neulet.2008.06.024

Buse, L., & Pawlik, K. (1984). Inter-Setting-Korrelationen und Setting-Persönlichkeit-Wechselwirkungen: Ergebnisse einer Felduntersuchung zur Konsistenz von Verhalten und Erleben. *Zeitschrift für Sozialpsychologie, 15,* 44–59.

Bussmann, J. B., & Ebner-Priemer, U. W. (2012). Ambulatory assessment of movement behavior: Methodology, measurement, and application. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 235–250). New York: Guilford Press.

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental neuropsychology, 28,* 595–616. doi:10.1207/s15326942dn2802_3

Carstensen, L. L., Turan, B., Scheibe, S., Ram, N., Ersner-Hershfield, H., Samanez-Larkin, G. R., . . . Nesselroade, J. R. (2011). Emotional experience improves with age: Evidence based on over 10 years of experience sampling. *Psychology and Aging, 26,* 21–33. doi:10.1037/a0021285

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100,* 126–131.

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research, 1453,* 87–101. doi:10.1016/j.brainres.2012.02.068

Chang, Y.-K., Liu, S., Yu, H.-H., & Lee, Y.-H. (2012). Effect of acute exercise on executive function in children with attention deficit hyperactivity disorder. *Archives of Clinical Neuropsychology: The Official Journal of the National Academy of Neuropsychologists, 27,* 225–237. doi:10.1093/arclin/acr094

Ciairano, S., Visu-Petra, L., & Settanni, M. (2007). Executive inhibitory control and cooperative behavior during early school years: A follow-up study. *Journal of Abnormal Child Psychology, 35,* 335–345. doi:10.1007/s10802-006-9094-z

Cohen, S., Doyle, W. J., Turner, R. B., Alper, C. M., & Skoner, D. P. (2003). Emotional style and susceptibility to the common cold. *Psychosomatic Medicine, 65,* 652–657. doi:10.1097/01.PSY.0000077508.57784.DA

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science, 14,* 125–130.

Conn, V. S. (2010). Depressive symptom outcomes of physical activity interventions: Meta-analysis findings. *Annals of Behavioral Medicine, 39,* 128–138. doi:10.1007/s12160-010-9172-x

Cooper, S. B., Bandelow, S., Nute, M. L., Morris, J. G., & Nevill, M. E. (2012). The effects of a mid-morning bout of exercise on adolescents' cognitive function. *Mental Health and Physical Activity, 5,* 183–190. doi:10.1016/j.mhpa.2012.10.002

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., . . . Oja, P. (2003). International physical activity questionnaire: 12-country

reliability and validity. *Medicine & Science in Sports & Exercise, 35,* 1381–1395. doi:10.1249/01.MSS.0000078924.61453.FB

Cranford, J. A., Shrout, P. E., Iida, M., Rafaeli, E., Yip, T., & Bolger, N. (2006). A procedure for evaluating sensitivity to within-person change: Can mood measures in diary studies detect change reliably? *Personality and Social Psychology Bulletin, 32,* 917–929. doi:10.1177/0146167206287721

Davis, C. L., & Lambourne, K. (2009). Exercise and cognition in children. In T. McMorris, P. D. Tomporowski, & M. Audiffren (Eds.), *Exercise and Cognitive Function* (pp. 249–267). Chichester, UK, Hoboken, NJ: Wiley-Heinrich.

de Bock, F., Menze, J., Becker, S., Litaker, D., Fischer, J., & Seidel, I. (2010). Combining accelerometry and HR for assessing preschoolers' physical activity. *Medicine and Science in Sports and Exercise, 42,* 2237–2243. doi:10.1249/MSS.0b013e3181e27b5d

Deslandes, A., Moraes, H., Ferreira, C., Veiga, H., Silveira, H., Mouta, R., . . . Laks, J. (2009). Exercise and mental health: many reasons to move. *Neuropsychobiology, 59,* 191–198. doi:10.1159/000223730

Diamond, A. (2000). Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Development, 71,* 44–56. doi:10.1111/1467-8624.00117

Diamond, A. (2006). The early development of executive functions. In E. Bialystok & F. Craik (Eds.), *Lifespan cognition: Mechanisms of change* (pp. 70–95). New York: Oxford University Press.

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science, 333*(6045), 959–964. doi:10.1126/science.1204529

Diener, E., & Chan, M. Y. (2011). Happy people live longer: Subjective well-being contributes to health and longevity. *Applied Psychology: Health and Well-Being, 3,* 1–43. doi:10.1111/j.1758-0854.2010.01045.x

Dietrich, A., & Audiffren, M. (2011). The reticular-activating hypofrontality (RAH) model of acute exercise. *Neuroscience and Biobehavioral Reviews, 35,* 1305–1325. doi:10.1016/j.neubiorev.2011.02.001

Dishman, R. K., & O'Connor, P. J. (2009). Lessons in exercise neurobiology: The case of endorphins. *Mental Health and Physical Activity, 2,* 4–9. doi:10.1016/j.mhpa.2009.01.002

Dunn, A. L., Trivedi, M. H., & O'Neal, H. A. (2001). Physical activity dose-response effects on outcomes of depression and anxiety. *Medicine & Science in Sports & Exercise, 33*, S587–597.

Dunton, G. F., Liao, Y., Intille, S., Huh, J., & Leventhal, A. (2015). Momentary assessment of contextual influences on affective response during physical activity. *Health Psychology, 34*, 1145–1153. doi:10.1037/hea0000223

Ebner-Priemer, U. W., & Trull, T. J. (2009). Ambulatory assessment: An innovative and promising approach for clinical psychology. *European Psychologist, 14*, 109–119. doi:10.1027/1016-9040.14.2.109

Ekkekakis, P. (2013). *The measurement of affect, mood, and emotion: A guide for health-behavioral research*. Cambridge, UK, New York: Cambridge University Press.

Ellemberg, D., & St-Louis-Deschênes, M. (2010). The effect of acute physical exercise on cognitive function during development. *Psychology of Sport and Exercise, 11*, 122–126. doi:10.1016/j.psychsport.2009.09.006

European Working Group. (2008). *EU-Leitlinien für körperliche Aktivität [European guidelines for physical activity]*. Retrieved from http://ec.europa.eu/sport/library/policy_documents/eu-physical-activity-guidelines-2008_de.pdf

Eyre, H., & Baune, B. T. (2012). Neuroplastic changes in depression: A role for the immune system. *Psychoneuroendocrinology, 37*, 1397–1416. doi:10.1016/j.psyneuen.2012.03.019

Fahrenberg, J., Myrtek, M., Pawlik, K., & Perrez, M. (2007). Ambulatory assessment - monitoring behavior in daily life settings. *European Journal of Psychological Assessment, 23*, 206–213. doi:10.1027/1015-5759.23.4.206

Fedewa, A. L., & Ahn, S. (2011). The effects of physical activity and physical fitness on children's achievement and cognitive outcomes. *Research Quarterly for Exercise and Sport, 82*, 521–535. doi:10.1080/02701367.2011.10599785

Focht, B. C. (2009). Brief walks in outdoor and laboratory environments. *Research Quarterly for Exercise and Sport, 80*, 611–620. doi:10.1080/02701367.2009.10599600

Fortier, M. S., Guerin, E., Williams, T., & Strachan, S. (2015). Should I exercise or sleep to feel better?: A daily analysis with physically active working mothers. *Mental Health and Physical Activity, 8*, 56–61. doi:10.1016/j.mhpa.2015.03.001

Freedson, P. S., & Miller, K. (2000). Objective monitoring of physical activity using motion sensors and heart rate. *Research Quarterly for Exercise and Sport, 71*(*Suppl.* 2), 21–29. doi:10.1080/02701367.2000.11082782

Frijda, N. H. (2009). Mood. In D. Sander & K. R. Scherer (Eds.), *The Oxford companion to emotion and the affective sciences* (pp. 258–259). New York: Oxford University Press.

Galderisi, S., Heinz, A., Kastrup, M., Beezhold, J., & Sartorius, N. (2015). Toward a new definition of mental health. *World Psychiatry, 14*, 231–233. doi:10.1002/wps.20231

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin, 134*, 31–60. doi:10.1037/0033-2909.134.1.31

Gawrilow, C., Morgenroth, K., Schultz, R., Oettingen, G., & Gollwitzer, P. M. (2013). Mental contrasting with implementation intentions enhances self-regulation of goal pursuit in schoolchildren at risk for ADHD. *Motivation and Emotion, 37*, 134–145. doi:10.1007/s11031-012-9288-3

Gawrilow, C., Stadler, G., Langguth, N., Naumann, A., & Boeck, A. (2016). Physical activity, affect, and cognition in children with symptoms of ADHD. *Journal of Attention Disorders, 20*, 151–162. doi:10.1177/1087054713493318

Giacobbi, P. R., Hausenblas, H. A., & Frye, N. (2005). A naturalistic assessment of the relationship between personality, daily life events, leisure-time exercise, and mood. *Psychology of Sport and Exercise, 6*, 67–81. doi:10.1016/j.psychsport.2003.10.009

Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: A framework for conceptualizing the effects of various practice conditions in motor learning. *Journal of Motor Behavior, 36*, 212–224. doi:10.3200/JMBR.36.2.212-224

Hamaker, E. L. (2012). Why researchers should think "within-person": A paradigmatic rationale. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 43–61). New York: Guilford Press.

Hasselhorn, M., Schneider, W., & Trautwein, U. (Hrsg.). (2014). *Tests und Trends: Vol. 12. Lernverlaufsdiagnostik*. Göttingen: Hogrefe.

Heckler, B., & Croce, R. (1992). Effects of time of posttest after two durations of exercise on speed and accuracy of addition and subtraction by fit and less-fit

women. *Perceptual and Motor Skills, 75*, 1059–1065. doi:10.2466/pms.1992.75.3f.1059

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*, 58–65. doi:10.1038/nrn2298

Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience, 159*, 1044–1054. doi:10.1016/j.neuroscience.2009.01.057

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences, 16*, 174–180. doi:10.1016/j.tics.2012.01.006

Hötting, K., & Röder, B. (2013). Beneficial effects of physical exercise on neuroplasticity and cognition. *Neuroscience and Biobehavioral Reviews, 37*, 2243–2257. doi:10.1016/j.neubiorev.2013.04.005

Hubley, A. M., & Zumbo, B. D. (2013). Psychometric characteristics of assessment procedures: An overview. In K. F. Geisinger & B. A. Bracken (Eds.), *APA Handbook of testing and assessment in psychology* (pp. 3–19). Washington: American Psychological Association.

Hyde, A. L., Conroy, D. E., Pincus, A. L., & Ram, N. (2011). Unpacking the feel good effect of free-time physical activity: Between- and within-person associations with pleasant-activated feeling states. *Journal of Sport & Exercise Psychology, 33*, 884–902.

Izard, C. E. (1993). Organizational and motivational functions of discrete emotions. In M. Lewis & J. M. Haviland-Jones (Eds.), *Handbook of Emotions* (pp. 631–641). New York: Guilford Press.

Jacobs, N., Myin-Germeys, I., Derom, C., Delespaul, P., van Os, J., & Nicolson, N. A. (2007). A momentary assessment study of the relationship between affective and adrenocortical stress responses in daily life. *Biological Psychology, 74*, 60–66. doi:10.1016/j.biopsycho.2006.07.002

Jäger, K., Schmidt, M., Conzelmann, A., & Roebers, C. M. (2014). Cognitive and physiological effects of an acute physical activity intervention in elementary school children. *Frontiers in Psychology, 5*(1473). doi:10.3389/fpsyg.2014.01473

Jäger, K., Schmidt, M., Conzelmann, A., & Roebers, C. M. (2015). The effects of qualitatively different acute physical activity interventions in real-world settings on executive functions in preadolescent children. *Mental Health and Physical Activity, 9,* 1–9. doi:10.1016/j.mhpa.2015.05.002

Janssen, I., & Leblanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 7*(40). doi:10.1186/1479-5868-7-40

Kanning, M. (2013). Using objective, real-time measures to investigate the effect of actual physical activity on affective states in everyday life differentiating the contexts of working and leisure time in a sample with students. *Frontiers in Psychology, 3*(602). doi:10.3389/fpsyg.2012.00602

Kanning, M., & Schlicht, W. (2010). Be active and become happy: An ecological momentary assessment of physical activity and mood. *Journal of Sport & Exercise Psychology, 32,* 253–261. doi:10.1123/jsep.32.2.253

Kanning, M., Ebner-Priemer, U., & Schlicht, W. (2015). Using activity triggered e-diaries to reveal the associations between physical activity and affective states in older adult's daily living. *The International Journal of Behavioral Nutrition and Physical Activity, 12*(111). doi:10.1186/s12966-015-0272-7

Kelly, L. A., McMillan, D. G., Anderson, A., Fippinger, M., Fillerup, G., & Rider, J. (2013). Validity of actigraphs uniaxial and triaxial accelerometers for assessment of physical activity in adults in laboratory conditions. *BMC Medical Physics, 13*(5). doi:10.1186/1756-6649-13-5

Kiecolt-Glaser, J. K., McGuire, L., Robles, T. F., & Glaser, R. (2002). Emotions, morbidity, and mortality: New perspectives from psychoneuroimmunology. *Annual Review of Psychology, 53,* 83–107. doi:10.1146/annurev.psych.53.100901.135217

Knaepen, K., Goekint, M., Heyman, E. M., & Meeusen, R. (2010). Neuroplasticity – Exercise-Induced response of peripheral brain-derived neurotrophic factor. *Sports Medicine, 40,* 765–801. doi:10.2165/11534530-000000000-00000

Kohl, H. W., Fulton, J. E., & Caspersen, C. J. (2000). Assessment of physical activity among children and adolescents: A review and synthesis. *Preventive Medicine, 31,* S54–S76. doi:10.1006/pmed.1999.0542

Könen, T., Dirk, J., & Schmiedek, F. (2015). Cognitive benefits of last night's sleep: Daily variations in children's sleep behavior are related to working memory fluctuations. *Journal of Child Psychology and Psychiatry, 56*, 171–182. doi:10.1111/jcpp.12296

Kredlow, M. A., Capozzoli, M. C., Hearon, B. A., Calkins, A. W., & Otto, M. W. (2015). The effects of physical activity on sleep: A meta-analytic review. *Journal of Behavioral Medicine, 38*, 427–449. doi:10.1007/s10865-015-9617-6

Lambourne, K., & Tomporowski, P. (2010). The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Research, 1341*, 12–24. doi:10.1016/j.brainres.2010.03.091

Lampert, T., Mensink, G. B. M., & Muters, S. (2012). Körperlich-sportliche Aktivität bei Erwachsenen in Deutschland. Ergebnisse der Studie "Gesundheit in Deutschland aktuell 2009" [Physical and sporting activity among adults in Germany. Results from the "German Health Update 2009" survey]. *Bundesgesundheitsblatt, 55*, 102–110. doi:10.1007/s00103-011-1401-3

Langguth, N., Schmid, J., Gawrilow, C., & Stadler, G. (2016). Within-person link between depressed affect and moderate-to-vigorous physical activity in adolescence: An intensive longitudinal approach. *Applied Psychology: Health and Well-Being, 8*, 44–63. doi:10.1111/aphw.12061

Lee, S., Jeong, J., Kwak, Y., & Park, S. K. (2010). Depression research: Where are we now? *Molecular Brain, 3*(8). doi:10.1186/1756-6606-3-8

Lehnert, K., Sudeck, G., & Conzelmann, A. (2012). Subjective well-being and exercise in the second half of life: A critical review of theoretical approaches. *European Review of Aging and Physical Activity, 9*, 87–102. doi:10.1007/s11556-012-0095-3

Lehto, J. E., Juujarvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology, 21*, 59–80. doi:10.1348/026151003321164627

Liao, Y., Shonkoff, E. T., & Dunton, G. F. (2015). The acute relationships between affect, physical feeling states, and physical activity in daily life: A review of current evidence. *Frontiers in Psychology, 6*(1975). doi:10.3389/fpsyg.2015.01975

Maher, J. P., Doerksen, S. E., Elavsky, S., Hyde, A. L., Pincus, A. L., Ram, N., & Conroy, D. E. (2013). A daily analysis of physical activity and satisfaction with life in emerging adults. *Health Psychology, 32*, 647–656. doi:10.1037/a0030129

Mahon, A. D., Marjerrison, A. D., Lee, J. D., Woodruff, M. E., & Hanna, L. E. (2010). Evaluating the prediction of maximal heart rate in children and adolescents. *Research Quarterly for Exercise & Sport, 81*, 466–471. doi:10.1080/02701367.2010.10599707

Mammen, G., & Faulkner, G. (2013). Physical activity and the prevention of depression: A systematic review of prospective studies. *American Journal of Preventive Medicine, 45*, 649–657. doi:10.1016/j.amepre.2013.08.001

Mata, J., Thompson, R. J., & Gotlib, I. H. (2010). BDNF genotype moderates the relation between physical activity and depressive symptoms. *Health Psychology, 29*, 130–133. doi:10.1037/a0017261

Mata, J., Thompson, R. J., Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Gotlib, I. H. (2012). Walk on the bright side: Physical activity and affect in major depressive disorder. *Journal of Abnormal Psychology, 121*, 297–308. doi:10.1037/a0023533

McMinn, D., Acharya, R., Rowe, D. A., Gray, S. R., & Allan, J. L. (2013). Measuring activity energy expenditure: Accuracy of the GT3X+ and Actiheart monitors. *International Journal of Exercise Science, 6*, 217–229. Retrieved from http://digitalcommons.wku.edu/ijes/vol6/iss3/5

McMorris, T., & Hale, B. J. (2012). Differential effects of differing intensities of acute exercise on speed and accuracy of cognition: A meta-analytical investigation. *Brain and Cognition, 80*, 338–351. doi:10.1016/j.bandc.2012.09.001

McNair, D. M., Lorr, M., & Droppleman, L. F. (1992). *EdITS manual for the profile of mood states*. San Diego, CA: Educational and Industrial Testing Services.

Mierau, A., Hulsdunker, T., Mierau, J., Hense, A., Hense, J., & Struder, H. K. (2014). Acute exercise induces cortical inhibition and reduces arousal in response to visual stimulation in young children. *International Journal of Developmental Neuroscience, 34*, 1–8. doi:10.1016/j.ijdevneu.2013.12.009

Miller, G. (2012). The smartphone psychology manifesto. *Perspectives on Psychological Science, 7*, 221–237. doi:10.1177/1745691612441215

KM BW = Ministerium für Kultus, Jugend und Sport Baden-Württemberg. (2011). *Orientierungsplan für Bildung und Erziehung in Baden-Württembergischen*

Kindergärten und weiteren Kindertageseinrichtungen [Educational plan for early educational institutions in Baden-Wuerttemberg, Germany]. Retrieved from http://www.km-bw.de/site/pbs-bw-new/get/documents/KULTUS.Dachmandant/KULTUS/Projekte/kindergaerten-bw/Oplan/Material/KM-KIGA_Orientierungsplan_2011.pdf

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100. doi:10.1006/cogp.1999.0734

Molenaar, P. C., & Campbell, C. G. (2009). The new person-specific paradigm in psychology. *Current Directions in Psychological Science, 18*, 112–117. doi:10.1111/j.1467-8721.2009.01619.x

Moraine, J. J., Lamotte, M., Berre, J., Niset, G., Leduc, A., & Naeije, R. (1993). Relationship of middle cerebral artery blood flow velocity to intensity during dynamic exercise in normal subjects. *European Journal of Applied Physiology and Occupational Physiology, 67*, 35–38. doi:10.1007/BF00377701

Netz, Y., Wu, M.-J., Becker, B. J., & Tenenbaum, G. (2005). Physical activity and psychological well-being in advanced age: A meta-analysis of intervention studies. *Psychology and Aging, 20*, 272–284. doi:10.1037/0882-7974.20.2.272

Neumaier, A. (2006). *Koordinatives Anforderungsprofil und Koordinationstraining: Grundlagen, Analyse, Methodik* [Coordination demands and coordination training: Bases, analyses, methods] (3. Aufl.). Köln: Sportverlag Strauß.

Palmer, K. K., Miller, M., & Robinson, L. E. (2013). Acute exercise enhances preschoolers' ability to sustain attention. *Journal of Sport & Exercise Psychology, 35*, 433–437. doi:10.1123/jsep.35.4.433

Paluska, S. A., & Schwenk, T. L. (2000). Physical activity and mental health. *Sports Medicine, 29*, 167–180. doi:10.2165/00007256-200029030-00003

Parfitt, G., Rose, E. A., & Markland, D. (2000). The effect of prescribed and preferred intensity exercise on psychological affect and the influence of baseline measures of affect. *Journal of Health Psychology, 5*, 231–240. doi:10.1177/135910530000500213

Pesce, C. (2009). An integrated approach to the effect of acute and chronic exercise on cognition: The linked role of individual and task constraints. In T. McMorris, P.

D. Tomporowski, & M. Audiffren (Eds.), *Exercise and cognitive function* (pp. 213–225). Chichester, UK, Hoboken, NJ: Wiley-Heinrich.

Pesce, C. (2012). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of Sport & Exercise Psychology, 34*, 766–786. doi:10.1123/jsep.34.6.766

Petermann, F. (2008). *Movement assessment battery for children-2 (Movement ABC-2).* Frankfurt: Pearson PLC.

Petriwskyj, A., Thorpe, K., & Tayler, C. (2005). Trends in construction of transition to school in three western regions, 1990–2004. *International Journal of Early Years Education, 13*, 55–69. doi:10.1080/09669760500048360

Piaget, J., & Aebli, H. (1974). *Psychologie der Intelligenz [Psychology of Intelligence]* (6. Aufl.). Freiburg: Walter.

Pirrie, A. M., & Lodewyk, K. R. (2012). Investigating links between moderate-to-vigorous physical activity and cognitive performance in elementary school students. *Mental Health and Physical Activity, 5*, 93–98. doi:10.1016/j.mhpa.2012.04.001

Plasqui, G., Bonomi, A. G., & Westerterp, K. R. (2013). Daily physical activity assessment with accelerometers: New insights and validation studies. *Obesity Reviews, 14*, 451–462. doi:10.1111/obr.12021

Pontifex, M. B., Saliba, B. J., Raine, L. B., Picchietti, D. L., & Hillman, C. H. (2013). Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder. *The Journal of Pediatrics, 162*, 543–551. doi:10.1016/j.jpeds.2012.08.036

Poole, L., Steptoe, A., Wawrzyniak, A. J., Bostock, S., Mitchell, E. S., & Hamer, M. (2011). Associations of objectively measured physical activity with daily mood ratings and psychophysiological stress responses in women. *Psychophysiology, 48*, 1165–1172. doi:10.1111/j.1469-8986.2011.01184.x

Posner, J., Russell, J. A., & Peterson, B. S. (2005). The circumplex model of affect: an integrative approach to affective neuroscience, cognitive development, and psychopathology. *Development and Psychopathology, 17*, 715–734. doi:10.1017/S0954579405050340

Preßler, A.-L., Könen, T., Hasselhorn, M., & Krajewski, K. (2014). Cognitive preconditions of early reading and spelling: A latent-variable approach with

longitudinal data. *Reading and Writing, 27*, 383–406. doi:10.1007/s11145-013-9449-0

Prestwich, A., Conner, M., Hurling, R., Ayres, K., & Morris, B. (2016). An experimental test of control theory-based interventions for physical activity. *British Journal of Health Psychology, 21*, 812–826. doi:10.1111/bjhp.12198

Prince, S. A., Adamo, K. B., Hamel, M., Hardt, J., Connor Gorber, S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity, 5*(56). doi:10.1186/1479-5868-5-56

Puetz, T. W., O'Connor, P. J., & Dishman, R. K. (2006). Effects of chronic exercise on feelings of energy and fatigue: A quantitative synthesis. *Psychological Bulletin, 132*, 866–876. doi:10.1037/0033-2909.132.6.866

Reed, J., & Buck, S. (2009). The effect of regular aerobic exercise on positive-activated affect: A meta-analysis. *Psychology of Sport and Exercise, 10*, 581–594. doi:10.1016/j.psychsport.2009.05.009

Reis, H. T. (2012). Why researchers should think ‘real-world’: A conceptual rationale. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 3–21). New York: Guilford Press.

Rethorst, C. D., Wipfli, B. M., & Landers, D. M. (2009). The antidepressive effects of exercise: A meta-analysis of randomized trials. *Sports Medicine, 39*, 491–511. doi:10.2165/00007256-200939060-00004.

Rheinberg, F. (1983). Achievement evaluation: A fundamental difference and its motivational consequences. *Studies in Educational Evaluation, 9*, 185–194. doi:10.1016/0191-491X(83)90026-3

Rhodes, R. E., & Bruijn, G.-J. de. (2013). How big is the physical activity intention-behaviour gap? A meta-analysis using the action control framework. *British Journal of Health Psychology, 18*, 296–309. doi:10.1111/bjhp.12032

Rimer, J., Dwan, K., Lawlor, D. A., Greig, C. A., McMurdo, M., Morley, W., & Mead, G. E. (2012). Exercise for depression. *The Cochrane database of systematic reviews, 7*, CD004366. doi:10.1002/14651858.CD004366.pub5

Romine, C. B., & Reynolds, C. R. (2005). A model of the development of frontal lobe functioning: Findings from a meta-analysis. *Applied Neuropsychology, 12*, 190–201. doi:10.1207/s15324826an1204_2

Roth, K., Ruf, K., Obinger, M., Mauer, S., Ahnert, J., Schneider, W., . . . Hebestreit, H. (2010). Is there a secular decline in motor skills in preschool children? *Scandinavian Journal of Medicine & Science in Sports, 20,* 670–678. doi:10.1111/j.1600-0838.2009.00982.x

Röthlisberger, M., Neuenschwander, R., Cimeli, P., & Roebers, C. M. (2013). Executive functions in 5- to 8-year olds: Developmental changes and relationship to academic achievement. *Journal of Educational and Developmental Psychology, 3,* 153–167. doi:10.5539/jedp.v3n2p153

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review, 110,* 145–172. doi:10.1037/0033-295X.110.1.145

Russell, J. A., & Barrett, L. F. (1999). Core affect, prototypical emotional episodes, and other things called emotion: Dissecting the elephant. *Journal of Personality and Social Psychology, 76,* 805–819. doi:10.1037/0022-3514.76.5.805

Sasaki, J. E., John, D., & Freedson, P. S. (2011). Validation and comparison of ActiGraph activity monitors. *Journal of Science and Medicine in Sport, 14,* 411–416. doi:10.1016/j.jsams.2011.04.003

Schwarz, N. (2012). Why researchers should think 'real-time': A cognitive rationale. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 22–42). New York: Guilford Press.

Schwerdtfeger, A., Eberhardt, R., & Chmitorz, A. (2008). Gibt es einen Zusammenhang zwischen Bewegungsaktivität und psychischem Befinden im Alltag? [Is there a correlation between everyday-life physical activity and psychological well-being? A methodological study using ambulatory monitoring]. *Zeitschrift für Gesundheitspsychologie, 16,* 2–11. doi:10.1026/0943-8149.16.1.2

Schwerdtfeger, A., Eberhardt, R., Chmitorz, A., & Schaller, E. (2010). Momentary affect predicts bodily movement in daily life: An ambulatory monitoring study. *Journal of Sport & Exercise Psychology, 32,* 674–693. doi:10.1123/jsep.32.5.674

Serrien, D. J., Ivry, R. B., & Swinnen, S. P. (2007). The missing link between action and cognition. *Progress in Neurobiology, 82,* 95–107. doi:10.1016/j.pneurobio.2007.02.003

Shrout, P. E., & Lane, S. P. (2012). Psychometrics. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 302–320). New York: Guilford Press.

Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: a meta-analysis. *Pediatric Exercise Science, 15,* 243–256. doi:10.1123/pes.15.3.243

Sigmund, E., Ste Croix, M. de, Miklankova, L., & Fromel, K. (2007). Physical activity patterns of kindergarten children in comparison to teenagers and young adults. *European Journal of Public Health, 17,* 646–651. doi:10.1093/eurpub/ckm033

Singer, J. D., & Willett, J. B. (2003). *Applied longitudinal data analysis: Modeling change and event occurrence*. New York: Oxford University Press.

Sniehotta, F. F., Scholz, U., & Schwarzer, R. (2005). Bridging the intention-behaviour aap: Planning, self-efficacy, and action control in the adoption and maintenance of physical exercise. *Psychology & Health, 20,* 143–160. doi:10.1080/08870440512331317670

Society for Ambulatory Assessment. (n.d.). Retrieved from http://www.ambulatory-assessment.org

Spence, J. C., McGannon, K. R., & Poon, P. (2005). The effect of exercise on global self-esteem: A quantitative review. *Journal of Sport & Exercise Psychology, 27,* 311–335.

Stadler, G., Oettingen, G., & Gollwitzer, P. M. (2009). Physical activity in women: Effects of a self-regulation intervention. *American Journal of Preventive Medicine, 36,* 29–34. doi:10.1016/j.amepre.2008.09.021

Statista Survey. (2016). *Which of the following sports and fitness gadgets do you use on a regular basis?* Retrieved from https://www.statista.com/statistics/639484/sports-and-fitness-gadget-usage-in-us/.

Stavrakakis, N., Booij, S. H., Roest, A. M., Jonge, P. de, Oldehinkel, A. J., & Bos, E. H. (2015). Temporal dynamics of physical activity and affect in depressed and nondepressed individuals. *Health Psychology, 34* (*Suppl.*), 1268–1277. doi:10.1037/hea0000303

Stein, M. (2016). *Die Wirksamkeit chronischer und akuter sportlicher Aktivität auf die kognitiven Fähigkeiten von Vorschulkindern [Effectiveness of chronic and acute sports activities on preschooler's cognitive functions](Doctoral dissertation).* Retrieved from http://nbn-resolving.de/urn:nbn:de:hebis:34-2016102651117

Stone, A. A., Schwartz, J. E., Broderick, J. E., & Deaton, A. (2010). A snapshot of the age distribution of psychological well-being in the United States. *Proceedings of*

the National Academy of Sciences of the United States of America, 107, 9985–9990. doi:10.1073/pnas.1003744107

Strath, S. J., Kaminsky, L. A., Ainsworth, B. E., Ekelund, U., Freedson, P. S., Gary, R. A., . . . Swartz, A. M. (2013). Guide to the assessment of physical activity: Clinical and research applications: A scientific statement from the American Heart Association. *Circulation, 128*, 2259–2279. doi:10.1161/01.cir.0000435708.67487.da

Strath, S. J., Swartz, A. M., Bassett, D. R., JR, O'Brien, W. L., King, G. A., & Ainsworth, B. E. (2000). Evaluation of heart rate as a method for assessing moderate intensity physical activity. *Medicine & Science in Sports & Exercise, 32*(*Suppl.* 9), S465-70.

Suchodoletz, A. von, Trommsdorff, G., Heikamp, T., Wieber, F., & Gollwitzer, P. M. (2009). Transition to school: The role of kindergarten children's behavior regulation. *Learning and Individual Differences, 19*, 561–566. doi:10.1016/j.lindif.2009.07.006

Tomporowski, P. D., McCullick, B., Pendleton, D. M., & Pesce, C. (2015). Exercise and children's cognition: The role of exercise characteristics and a place for metacognition. *Journal of Sport and Health Science, 4*, 47–55. doi:10.1016/j.jshs.2014.09.003

Troiano, R. P., Berrigan, D., Dodd, K. W., Mâsse, L. C., Tilert, T., & McDowell, M. (2008). Physical activity in the United States measured by accelerometer. *Medicine & Science in Sports & Exercise, 40*, 181–188. doi:10.1249/mss.0b013e31815a51b3

Trull, T. J., & Ebner-Priemer, U. (2013). Ambulatory assessment. *Annual Review of Clinical Psychology, 9*, 151–176. doi:10.1146/annurev-clinpsy-050212-185510

Trull, T., & Ebner-Priemer, U. W. (2014). The role of ambulatory assessment in psychological science. *Current Directions in Psychological Science, 23*, 466–470. doi:10.1177/0963721414550706

Ursache, A., Blair, C., & Raver, C. C. (2012). The promotion of self-regulation as a means of enhancing school readiness and early achievement in children at risk for school failure. *Child Development Perspectives, 6*, 122–128. doi:10.1111/j.1750-8606.2011.00209.x

Vaynman, S., & Gomez-Pinilla, F. (2006). Revenge of the "sit": How lifestyle impacts neuronal and cognitive health through molecular systems that interface energy

metabolism with neuronal plasticity. *Journal of Neuroscience Research, 84*, 699–715. doi:10.1002/jnr.20979

Verburgh, L., Konigs, M., Scherder, E. J. A., & Oosterlaan, J. (2014). Physical exercise and executive functions in preadolescent children, adolescents and young adults: A meta-analysis. *British Journal of Sports Medicine, 48*, 973–979. doi:10.1136/bjsports-2012-091441

Voelcker-Rehage, C. (2005). Der Zusammenhang zwischen motorischer und kognitiver Entwicklung im frühen Kindesalter – Ein Teilergebnis der MODALIS-Studie [The association between motor and cognitive development in early childhood – Partial results from the MODALIS-study]. *Deutsche Zeitschrift für Sportmedizin, 56*, 358–363.

Warren, J. M., Ekelund, U., Besson, H., Mezzani, A., Geladas, N., & Vanhees, L. (2010). Assessment of physical activity - A review of methodologies with reference to epidemiological research: A report of the exercise physiology section of the European Association of Cardiovascular Prevention and Rehabilitation. *European Journal of Cardiovascular Prevention & Rehabilitation, 17*, 127–139. doi:10.1097/HJR.0b013e32832ed875

Weinstein, S. M., Mermelstein, R., Shiffman, S., & Flay, B. (2008). Mood variability and cigarette smoking escalation among adolescents. *Psychology of Addictive Behaviors, 22*, 504–513. doi:10.1037/0893-164X.22.4.504

Wichers, M., Peeters, F., Rutten, B. P. F., Jacobs, N., Derom, C., Thiery, E., . . . van Os, J. (2012). A time-lagged momentary assessment study on daily life physical activity and affect. *Health Psychology, 31*, 135–144. doi:10.1037/a0025688

Wilhelm, P., Perrez, M., & Pawlik, K. (2012). Conducting research in daily life: A historical review. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 62–86). New York: Guilford Press.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*, 625–636. doi:10.3758/BF03196322

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., . . . Knecht, S. (2007). High impact running improves learning. *Neurobiology of Learning and Memory, 87*, 597–609. doi:10.1016/j.nlm.2006.11.003

Wolf, S., & Hautzinger, M. (2012). Linderung depressiver Symptomatik. *Psychotherapeut, 57*, 241–247. doi:10.1007/s00278-011-0854-z

World Health Organization. (1992). *The ICD-10 classification of mental and behavioural disorders: Clinical descriptions and diagnostic guidelines*. Geneva, Switzerland: World Health Organization.

World Health Organization. (2013). *Investing in mental health: evidence for action.* Retrieved from http://apps.who.int/iris/bitstream/10665/87232/1/9789241564618_eng.pdf

World Health Organization. (2014). *10 facts on physical activity*. Retrieved from http://www.who.int/features/factfiles/physical_activity/en/

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, *18*, 459–482. doi:10.1002/cne.920180503

APPENDIX

A. Manuscript 1: Physical Activity and Affect in Young Adults' Daily Lives

Haas, P., Schmid, J., Stadler, G., Reuter, M., & Gawrilow, C. (in press). Zooming into daily life: Within-person associations between physical activity and affect in young adults. *Psychology & Health.*

This is an Accepted Manuscript of an article published by Taylor & Francis in *Psychology & Health* on 27/02/17 (online), available online: http://wwww.tandfonline.com/10.1080/08870446.2017.1291943

Zooming into Daily Life: Within-Person Associations Between Physical Activity and Affect in Young Adults

Petra Haas[1], Johanna Schmid[1,2,3], Gertraud Stadler[4,5], Merle Reuter[2], & Caterina Gawrilow[1,2,3]

[1]*LEAD Graduate School & Research Network, Eberhard Karls Universität Tübingen, Germany;*
[2]*Department of Psychology, Eberhard Karls Universität Tübingen, Germany;*
[3]*Center for Research on Individual Developmental and Adaptive Education of Children at Risk (IDeA-Center), Frankfurt, Germany;*
[4]*Department of Applied Health Sciences, University of Aberdeen, United Kingdom;*
[5]*Department of Psychology, Columbia University, United States*

Corresponding author:
Petra Haas
Eberhard Karls Universität Tübingen
LEAD Graduate School and Research Network
Gartenstraße 29
72074 Tübingen, Germany
0049 7071 2975546
petra.haas@uni-tuebingen.de

Zooming into Daily Life: Within-Person Associations Between Physical Activity and Affect in Young Adults

Objective: Negative affect in daily life is linked to poorer mental and physical health. Activity could serve as an effective, low-cost intervention to improve affect. However, few prior studies have assessed physical activity and affect in everyday life, limiting the ecological validity of prior findings. This study investigates whether daily activity is associated with negative and positive evening affect in young adults.
Design: Young adults (N = 189, Mdn = 23.00) participated in an intensive longitudinal study over 10 consecutive days.
Main Outcome Measures: Participants wore accelerometers to objectively assess moderate-to-vigorous physical activity continuously throughout the day and reported their affect in time-stamped online evening diaries before going to sleep.
Results: On days when participants engaged in more activity than usual, they reported not only less depressed and angry evening affect but also more vigor and serenity in the evening.
Conclusion: Young adults showed both less negative and more positive affect on days with more activity. Physical activity is a promising health promotion strategy for physical and mental well-being.

Keywords: accelerometry; affect; physical activity; intensive longitudinal design; within-person association

Running head: Physical activity and affect within persons

Introduction

How we feel is crucial for mental and physical health. Transient and subjective episodes of feelings that can be easily changed by context constitute affect (Cranford et al., 2006). Negative affect (e.g., depressed, angry, and anxious affect) in everyday life is associated with poorer mental and physical health (Charles, Piazza, Mogle, Sliwinski, & Almeida, 2013; Kiecolt-Glaser, McGuire, Robles, & Glaser, 2002). Positive affect (e.g., vigor, serenity) in everyday life is associated with, for instance, longevity (Diener & Chan, 2011).

Short-term fluctuations in negative and positive affect from day to day or within days are a common phenomenon (Eid & Diener, 1999). In addition, during early adulthood (between 20 and 30 years of age), negative affect is reported more frequently (Stone, Schwartz, Broderick, & Deaton, 2010) and positive affect is lower than in later adulthood (Carstensen et al., 2011). Because of the association between affect in everyday life and health, this age group is the focus of the present study. Identifying processes that may help young adults improve their everyday affective experiences is important for both individuals (e.g., to improve health and well-being) and for society (e.g., to reduce health care costs) and may have benefits for health promotion.

Prior studies on the association between physical activity and affect

Physical activity is "any bodily movement […] that requires energy expenditure" (World Health Organization [WHO], 2010, p.53) and a low-cost and easily accessible intervention with multiple beneficial effects. National and international health boards recommend engaging in at least 30 minutes of moderate activity 5 days per week for primary prevention of chronic disease (American Health Association, 2014; European Working Group, 2008). Meta-analyses demonstrate that physical activity interventions reduce negative affect with small to moderate effect sizes in clinical and non-clinical adult samples (e.g., depressed samples: Lawlor & Hopker, 2001; Rimer et al., 2012; healthy samples: Conn, 2010). Importantly, the intensity and frequency of physical activity seem to moderate the effect on affect (Dunn, Trivedi, & O'Neal, 2001). Engaging regularly in *moderate-to-vigorous* physical activity has been linked to reduced negative affect in cross-sectional studies (e.g., Poole et al., 2011), longitudinal studies (e.g., Mammen & Faulkner, 2013) and intervention studies (e.g., Parfitt, Rose, & Markland, 2000). So far, however, the association between physical activity and positive affect has been studied less frequently. Two meta-analyses suggest

that physical activity interventions of low to moderate intensity increase positive affect (Puetz, O'Connor, & Dishman, 2006; Reed & Buck, 2009). Additionally, studies addressing fatigue, which we refer to as a slight negative feeling of lacking energy, are rather rare. One meta-analysis indicates that regular physical activity is associated with less fatigue (Puetz et al., 2006). Potential mechanisms that are discussed as drivers of the positive influence of physical activity on affect are physiological processes (e.g., increased neuroplasticity; Eyre & Baune, 2012) and psychological processes (e.g., increased self-efficacy; Ryan, 2008; for an overview, see Lehnert, Sudeck, & Conzelmann, 2012), with the joint effects of these processes still in dispute.

In sum, previous research has supported the notion of benefits of physical activity interventions in decreasing negative affect and provided initial evidence in terms of increasing positive affect. To derive implications for health promotion and enrich current activity recommendations, it is important to analyze the interrelations between activity and affect in young adults' everyday lives.

The challenge of studying activity and affect within persons in everyday life

The studies reviewed so far are based on comparisons between persons (i.e., cross-sectional studies, e.g., Poole et al., 2011) and activity intervention studies (e.g., Conn, 2010). The generalizability of these prior results on the activity-affect association in everyday life may be limited for the following reasons. First, physical activity was often assessed using self-reports of past activity, which overestimate the actual amount of activity compared to objective measures of activity (e.g., accelerometers; Prince et al., 2008) and may be prone to recall bias. Second, experimentally manipulated, directed and supervised physical activity, as is commonly applied in interventions studies (e.g., Conn, 2010), is likely quite different from naturally occurring self-initiated activity in everyday life. In everyday life, people engage in structured activities (e.g., going to the gym) as well as unstructured spontaneous activities (e.g., commuting, household chores) that add up to a total daily amount of activity. Whether naturally occurring self-initiated activity is linked to affect has rarely been studied (for an exception, see Kanning, Ebner-Priemer, & Schlicht, 2013). Moreover, the generalizability of prior results on the activity-affect association at the within-person level may also be limited: Cross-sectional results on the activity-affect association are based on comparisons between persons, showing, for instance, that persons who habitually engage more often in physical activity report more positive affect than less active persons (e.g., Pasco et

al., 2011). These results, however, cannot be directly transferred to the within-person level because associations at the between-person and within-person level may differ and may even go in opposite directions–(Hamaker, 2012; Molenaar & Campbell, 2009). Thus, between-person results are not a valid source of information for inferring how physical activity and affect actually covary within persons across time in everyday life.

Importance of studying within-person associations between activity and affect in everyday life

The challenge of studying fluctuating experiences and behaviors within persons across time can optimally be met by *intensive longitudinal designs* where the same individuals are repeatedly assessed in their everyday lives (Bolger & Laurenceau, 2013). Intensive longitudinal designs are able to capture "life as it is lived" (Bolger, Davis, & Rafaeli, 2003, p. 580) and can further contribute to: (a) a more precise view of day-to-day changes in individuals' physical–activity and affect, as well as their association, due to assessments that approximate *real time*; (b) a description of naturally occurring physical activity and affect and thus more ecologically valid data that increases the generalizability of study results due to the fact that assessments were made in *real life*; and (c) conclusions about within-person processes due to repeated assessments *within individuals* (Fahrenberg, Myrtek, Pawlik, & Perrez, 2007; Reis, 2012).

So far, only a few studies have addressed the within-person association between physical activity and negative affect in everyday life revealing mixed findings (for a review, see Liao, Shonkoff, & Dunton, 2015). In adolescents, two studies found within-person associations between objectively assessed activity and reduced negative same-evening affect (Gawrilow, Stadler, Langguth, Naumann, & Boeck, 2016) and reduced negative next-morning affect for female participants (Langguth, Schmid, Gawrilow, & Stadler, 2016). Some studies have shown no association between activity and negative affect on the within-person level in healthy adult samples (Giacobbi, Hausenblas, & Frye, 2005; Hyde, Conroy, Pincus, & Ram, 2011; Kanning, Ebner-Priemer, & Schlicht, 2015; Schwerdtfeger, Eberhardt, & Chmitorz, 2008; Wichers et al., 2012). In an assessment of participants with and without depression, self-reported daily activity was not associated with negative affect in either group (Mata et al., 2012). Methodological limitations, such as the self-reporting of physical activity and the insensitivity of affect

measures (i.e., in detecting short-term fluctuations in affect) may explain the non-significant findings in some of these studies.

Positive affect has been studied less frequently, with some studies demonstrating that self-reported episodes of activity are associated with increased positive affect (Fortier, Guerin, Williams, & Strachan, 2015; Hyde et al., 2011 ; Kanning & Schlicht, 2010; Maher et al., 2013; Mata et al., 2012; Wichers et al., 2012). This finding is corroborated by two studies showing a within-person association between increases in activity objectively measured via accelerometers and improved positive affect within or across days (Kanning, 2013; Schwerdtfeger et al., 2008). Moreover, a few studies in everyday life have provided initial evidence that activity is linked to less fatigue (Kanning, 2013; Kanning et al., 2015).

The present study

To date, only a few studies have provided evidence on the association between activity and negative/positive affect on the within-person level in everyday life. Many of the available within-person studies focus on momentary activity effects (within one day or across only a few days; e.g., Kanning, 2013; Schwertdfeger et al., 2008; Wichers et al., 2012) although national and international activity recommendations refer to a daily activity level (i.e., 30 minutes of moderate activity 5 days per week; American Health Association, 2014; European Working Group, 2008). Whether this recommended daily activity level is associated with improved affect has rarely been studied so far (for exceptions, see Gawrilow et al., 2016). However, evidence of daily activity effects on affect can help to further promote activity programs. Thus, the present study investigates daily levels of objectively recorded activity across 10 study days.

Regarding the assessment of affect, the effects of activity have mostly been studied for either negative or positive affect (e.g., Gawrilow et al., 2016; Langguth et al., 2016; Maher et al., 2013). However, subjective experiences and theoretical arguments favour a more nuanced picture of affect beyond just negative and positive affect. For example, Posner, Russell, and Peterson (2005) distinguished between unpleasant-deactivated (e.g., depressed affect, fatigue), unpleasant-activated (e.g., angry, anxious affect), pleasant-activated (e.g., vigor) and pleasant-deactivated (e.g., serenity) affects. The few existing studies assessing both positive and negative affect (e.g., Mata et al., 2012; Schwerdtfeger et al., 2008; Wichers et al., 2012) did not

differentiate between unpleasant and pleasant affects of varying activation levels (e.g., angry vs. depressed affect, vigor vs. serenity) or assessed physical activity with subjective reports (Hyde et al., 2011). By assessing affect in a more nuanced way, the present study extends past results by elucidating how activity is associated with specific affects.

Hypotheses and contributions of the present study

The present study investigated whether objectively assessed moderate-to-vigorous physical activity (from now on referred to as *activity*) in young adults throughout the day is associated with same-evening affect within persons. We expected more activity than usual on a given day to be associated with less negative affect (i.e., depressed, angry, and anxious affect) and higher positive affect (i.e., vigor, serenity) on the same evening. Moreover, we explored whether more activity than usual on a given day is associated with fatigue.

With these research questions, this study promises to address two main gaps in the current literature. First, the study findings are relevant for informing existing national and international guidelines (American Health Association, 2014; European working group, 2008) that recommend daily physical activity although few studies have actually examined the effects of daily activity. Prior evidence is mainly based on cross-sectional, longitudinal or intervention studies. By studying the effect of daily physical activity on evening affect, we will further add to the evidence base for these recommendations of daily activity. Second, another novel aspect of our study is the assessment of both positive and negative affect with varying levels of activation. Investigating the associations between objectively measured activity and specific unpleasant and pleasant affects of varying activation levels will reveal whether and how daily activity can serve as a tool for improving affect and thus, support effective health promotion.

Methods

Design and sample

In this intensive longitudinal study, young adults (N = 189) wore accelerometers and filled out daily diaries over 10 consecutive days[1]. Initially, 192 participants enrolled

[1] Ten days were chosen as study period to gain representative data across one full week including the weekend.

in the study; three participants were excluded due to technical problems with the accelerometer, non-completion of any diary entries or withdrawal from the study, resulting in 189 participating young adults (71% women, age: *Mdn* = 23.00, interquartile range = 7.00). The sample was highly educated, with nearly all participants holding a university entrance qualification (94%) and many enrolled as university students (76%). The present sample showed no elevated level of depressed affect (10.5% of participants above the cut-off point, comparable to 12% in a representative community sample; Hautzinger, Bailer, Hofmeister, & Keller, 2012) and had normal weight (body mass index: *M* = 22.28, *SD* = 2.61; normal weight range: 18.50-24.90; WHO, 2006). Participants were recruited in two data collection waves in Autumn 2013 and 2014 via flyers at a university in Germany as well as via word-of-mouth advertisement. All participants gave written informed consent to participate and received a €5 voucher or university credits for their participation. The study was approved by a national ethics review board (i.e., German Psychological Society).

Procedure

Using an intensive longitudinal design, we assessed activity continuously and affect states with daily evening diaries across 10 consecutive days. On Study Day 1 (i.e., Monday or Tuesday for most participants), participants met in small groups with two trained experimenters who summarized study procedures and measured participants' height and weight. At that point, each participant was provided with an accelerometer and activity measurement started. The study lasted until Study Day 10 (i.e., Wednesday or Thursday of the following week for most participants). Participants were instructed to wear the accelerometer during waking and sleeping hours but to remove it during water-based activities. The accelerometer was attached with a belt to participants' waistbands on the non-dominant side, ensuring valid measurement (McMinn, Acharya, Rowe, Gray, & Allan, 2013). On Study Day 1, participants received links to the online background questionnaire and to the first evening diary via email or text message, depending on their preference. Over the course of the study, they received daily links for the evening diaries. Participants were instructed to answer them right before going to sleep (i.e., Study Days 2 to 9).

Measures

Daily physical activity

This study focused on moderate-to-vigorous physical activity, which was measured continuously with triaxial accelerometers (4.6cm x 3.3cm x 1.5cm; model GT3X+; ActiGraph ®, Pensacola, FL, US) at a sampling rate of 60 Hz. Raw data were band-pass filtered with a frequency range of 0.25 to 2.50 Hz to detect normal human motion and aggregated into 60s-epochs using ActiLife 6 ®. To identify whether participants actually wore the accelerometer, we used a recently improved algorithm to distinguish between wear and non-wear time. Non-wear time refers to time intervals with consecutive zero counts for at least 90 min, while allowing up to 2 min of activity if no counts were detected during the 30 min both upstream and downstream of that interval based on records of the accelerometer's vertical axis (Choi, Liu, Matthews, & Buchowski, 2011). Wear-time validated data was scored with regard to cut-off points based on a vector magnitude that takes records on all three axes into account. This scoring resulted in a measure of participants' daily number of minutes spent in moderate-to-vigorous physical activity (> 2691 counts per minute; Sasaki, John, & Freedson, 2011). Participants with at least six hours of accelerometer wear time between filling out the morning[2] and evening diary entries (see Kühnhausen, Leonhardt, Dirk, & Schmiedek, 2013) and with at least four valid days out of eight study days were included in the analyses. When entries were missing, the mean time at which the participant made morning or evening diary entries was taken as the cut-off for the daily accelerometer wear time calculation.

Daily affect

Participants rated their current evening affect[3] using the *Profile of Mood States-15* (POMS-15; Cranford et al., 2006; McNair, Lorr, & Droppleman, 1992). We used a shortened version of the original POMS designed for repeated daily assessments to

[2] Apart from the evening diaries, we also asked participants to fill out morning diaries. However, the current study focuses solely on evening affect assessed in the evening diaries.

[3] Mood refers to "an affective state of long duration, low intensity, and a certain diffuseness" (Frijda, 2009, p. 258) and the original version of the Profile of Mood States (McNair, Lorr & Droppleman, 1992) instructs participants to answer how they felt during the last week including today. In contrast, affect can be seen as "a neurophysiological state that is consciously accessible as a simple, nonreflective feeling" (Russell, 2003, p. 147). This means that affect and mood can be differentiated by their temporal course. Therefore in this study we refer to affect since we measured current affect in daily life.

reliably detect within-person changes (Cranford et al., 2006). Participants answered each item ("How do you feel right now?") on a 5-point scale ranging from 1 (*not at all*) to 5 (*extremely*). The POMS-15 includes five affect scales with three items each: depressed affect (*sad, hopeless, discouraged*), angry affect (*angry, resentful, annoyed*), anxious affect (*anxious, on edge, uneasy*), vigor (*vigorous, cheerful, lively*), and fatigue (*fatigued, worn out, exhausted*). In order to take pleasant-deactivated affect into account, we also included a scale to assess serenity (*relaxed, calm, at ease*; Cohen, Doyle, Turner, Alper, & Skoner, 2003). Mean scores for each individual and each affect scale were calculated.

For all affect scales, we computed reliability estimates on the between-person level (i.e., referring to the reliability of individual differences in affect across study days), and on the within-person level (i.e., referring to the reliability of day-to-day affect fluctuations; Shrout & Lane, 2012). For evening affect, reliabilities on the between/within-person level were as follows: .94/.76 (depressed affect), .94/.83 (angry affect), .94/.66 (anxious affect), .96/.73 (vigor), .94/.71 (serenity) and .96/.76 (fatigue). These reliability estimates are in line with previously reported findings (e.g., Cranford et al., 2006).

Data analyses

Data preparation

We used activity and affect assessments from Study Days 2 to 9 (i.e., full study days). Days 1 and 10 were excluded because participants had to get used to wearing the accelerometer on the first day and brought back the accelerometer at individually selected time points on Day 10. Before analysing the diary data, we checked whether the time stamps registered online for each diary entry were in line with study protocol, as recommended (e.g., Shiffman, Stone, & Hufford, 2008). As participants were instructed to answer evening diaries before going to sleep, we considered all entries registered before 5:00 a.m. the next day as valid.

Within-person association between activity and evening affect

As a result of our intensive longitudinal design, repeated assessments are nested within participants. Thus, to analyze the within-person association between daily activity and same-evening affect, we used multilevel models (also called mixed-effects models, e.g., Singer & Willett, 2003). Random slope models were calculated for each

affect scale to test for a within-person association between activity and evening affect. We centered all time-varying variables at both the grand mean and the person mean, respectively, to decompose the effects of time-varying variables (e.g., daily activity) into their stable between-person part (e.g., *Activity-B*$_i$ indicates individual i's trait-like tendency to be more physically active than other participants) and their time-varying within-person part (e.g., *Activity-W*$_{ti}$ indicates individual i's state tendency on day t to be more physically active than usual). Equation 1 expresses a composite multilevel regression for testing our hypotheses:

$$Affect_{ti} = (\gamma_{00} + u_{0i}) + (\gamma_{10} + u_{1i})\,\text{Day}_{ti} + \gamma_{11}\text{WearTime}_{ti} + \gamma_{01}\text{Activity-B}_i + (\gamma_{12} + u_{2i})\,\text{Activity-W}_{ti} + \varepsilon_{it} \quad (1)$$

Evening affect of a participant *i* on day *t* is predicted by the following five fixed effects: (a) an intercept of affect, γ_{00}; (b) an average linear time trend indicating the change in affect over the study days, centered on Day 3, γ_{10}; (c) the participant's accelerometer wear time on a given day, γ_{11}; (d) the average activity of each participant across all study days, γ_{01}; and (e) the daily within-person fluctuation of each participant around their individual average activity, γ_{12}. Additionally, three random effects are included with mean 0 and variance *u* that account for individual shifts from the sample's average: (a) participant's deviation from the average intercept, u_{0i}; (b) participant's deviation from the average time trend, u_{1i}; and (c) participant's deviation from the average activity slope, u_{2i}. Importantly, the activity predictor on the within-person level tests the hypothesis that participants who engaged in more activity than usual over the course of one day (γ_{12}+ u_{2i}) show enhanced same-evening affect ($Affect_{ti}$). To account for the longitudinal data structure, we modeled time dependence of the residuals with a first-order autoregressive structure (*AR1*; Singer & Willett, 2003). All models were calculated with maximum likelihood estimation analyses and with a probability level of $p<.05$ to indicate significance using IBM SPSS Statistics 22 ®. The SPSS syntax used for the analyses is given in Appendix A.

Results

Compliance

Of 1,512 possible observations (i.e., 189 participants x 8 study days), we analyzed 1,377 observations with valid daily assessments of activity, and evening

affect. Overall, participants showed high compliance in terms of wearing accelerometers and filling out diary entries. Most participants (92%, n = 173) had a complete set of valid accelerometer wearing days from Study Day 2 to 9. On a valid day, participants wore the accelerometer for 14.12 hours (SD = 1.23) on average. With regard to valid diary entries (i.e., entries with time stamps in line with the study protocol), participants answered on average 7.40 evening diaries out of 8.00 possible entries. In addition, 86% of participants had at least 7 of 8 valid evening diary entries. On average, evening diaries were answered at 11:00 p.m. (SD = 62 min). In sensitivity analyses, we found no significant correlation above r = .12 (all p > .05) between any one indicator of valid observations and various background as well as daily assessed variables.

Descriptive statistics

To highlight the different levels of aggregation, descriptive statistics are presented in Table 1 separately for the between-person and within-person levels. The intraclass correlation coefficient (ICC) indicates how much of the variance originates on the between-person level and thus allows inferences to be made about the degree of variance attributable to within-person variation and a residual term (i.e., 1 - ICC). For all affect variables, at least 50% of variability cannot be accounted for by individual differences between persons, but occurs due to within-person variation and residual error, thus calling for multilevel analyses. For daily activity assessed with accelerometers, 77% of variability (i.e., 1 - 0.23) occurs due to fluctuations within persons and residual error. On average, participants reported moderate levels of vigor and fatigue and relatively low levels of anxious, angry and depressed affect in the evening diaries. Variability in affect ratings was present at the between-person and within-person levels, indicating that there were individual differences in mean affect ratings across the study period as well as fluctuations in each person's affect ratings from day to day. In total, participants engaged in about one hour of activity per day (59.19 min). The typical person's activity levels changed considerably from day to day (pooled within-person standard deviation for activity: SD = 31.60 min/day). [Table 1 near here]

Within-person association between activity and evening affect

Consistent with our hypotheses, we found significant negative within-person associations between activity and depressed as well as angry same-evening affect. On days where participants showed a 60-min increase in activity over their person mean, they also reported less depressed and less angry affect (both γ_{12} = -0.06). Surprisingly, more activity than usual was not significantly associated with less anxious same-evening affect.

In line with our hypotheses, we found significant positive within-person associations between activity and vigor as well as serenity in the evening. On days when participants showed a 60-min increase in activity over their person mean, they also reported more vigor (γ_{12} = 0.07) and more serenity (γ_{12} = 0.10).

Interestingly, more activity than usual was associated with higher same-evening fatigue. With a 60-min increase in activity over a participant's person mean, same-evening fatigue increased by 0.09 points (γ_{12}). Activity was also linked to evening fatigue on the between-person level. Participants who typically engaged in 60-min more activity than others showed 0.29 points (γ_{01}) less evening fatigue on average. In sensitivity analyses, we tested for effects of gender, age and weekday. There were no main effects of these variables in predicting evening affect, nor did they moderate the effects of activity on affect. Thus, we report the more parsimonious models without these covariates in Table 2. [Table 2 near here]

Discussion

This intensive longitudinal study in young adults showed that daily activity matters for affective well-being and thus supports national and international guidelines (American Health Association, 2014; European working group, 2008) recommending daily physical activity while few prior studies have actually examined the effects of daily activity. Using a strong research design including objectively assessed activity and daily online reports of positive and negative affect, the study found evidence that daily activity is associated with improved affect in the evening at the within-person level. On days when participants engaged in more activity than usual, they reported less depressed and less angry affect in the evening, but not less anxious affect. In addition, participants reported more vigor and more serenity in the evening on days with more activity than usual. Exploratory analyses showed that more activity than usual was linked to more same-evening fatigue.

First, our findings on the anti-depressant and anger-reducing associations of activity corroborate previous evidence from cross-sectional, longitudinal, and intervention studies (e.g., Conn, 2010; Mammen & Faulkner, 2013; Parfitt, Rose, & Markland, 2000; Poole et al., 2011; Puetz, O'Connor, & Dishman, 2006; Rimer et al., 2012), while often no significant association was found in within-person studies of adults (e.g., Giacobbi, Hausenblas, & Frye, 2005; Hyde et al., 2011; Kanning, 2013, et al., 2015; Liao et al., 2015; Mata et al., 2012; Schwerdtfeger, et al., 2008; Wichers et al., 2012). In line with studies in adolescent samples (e.g., Gawrilow et al., 2016; Langguth et al., 2016), the within-person effects of activity in the present study were relatively small. Importantly, even low levels of negative affect are relevant, as the measures for depressed and angry affect were designed to capture relatively intense negative affect (i.e., by introducing such items as *hopeless* or *resentful*). The generally low levels of negative affect in this healthy sample of young adults may account for the relatively small effects. However, the small effects in this study, found in everyday life and over the course of one day, may still be relevant, as experiences of slightly reduced negative affect could accumulate over time and have long-term implications for well-being. In contrast to the within-person associations between activity and the two negative affect scales depressed and angry affect, daily activity was not linked to anxious affect. This lack of a within-person association may be attributed to the relatively low within-person fluctuations in anxious evening affect (see Table 1).

For positive affect, we found evidence for a within-person association between activity and positive same-evening affect: more activity than usual was associated with more vigor and more serenity. These findings are in line with prior studies in everyday life (e.g., Fortier et al., 2015; Hyde et al., 2011; Kanning, 2013; Kanning & Schlicht, 2010; Maher et al., 2013; Mata et al., 2012; Schwerdtfeger et al., 2008; Wichers et al., 2012). Importantly, previous studies reporting significant within-person associations between physical activity and positive affect used sampling plans where participants indicated their momentary affect directly after being physically active (e.g., Kanning, 2013; Schwerdtfeger et al., 2008) and often did not differentiate between positive affects with varying levels of arousal (i.e., vigor vs. serenity; e.g., Mata et al., 2012; Schwerdtfeger et al., 2008; Wichers et al., 2012). Thus, the present findings yield first insights into daily activity effects and provide support for its benefits with regard to specific positive affects (i.e., vigor and serenity). However, an everyday life study with a small middle-aged adult sample and longer time lags between assessments (i.e.,

activity during the preceding 6 hours before affect measure) did not find a consistent association between activity and positive affect (Stavrakakis et al., 2015). Therefore, further replication studies in young adults are needed.

For fatigue, exploratory analyses revealed contrasting associations between activity and evening fatigue depending on the level of aggregation: (1) On the within-person level, days with more activity than usual were associated with higher same-evening fatigue, whereas (2) on the between-person level, participants who typically engaged in more activity than others reported less evening fatigue. First, our within-person finding is in contrast to some studies in everyday life that have found less fatigue but more energy after activity (e.g., Kanning, 2013). However, we assessed fatigue on a unipolar scale that might have teased apart feelings of energy and fatigue. In addition, higher evening fatigue after activity could benefit sleep quality (Kredlow, Capozzoli, Hearon, Calkins, & Otto, 2015) and thus be interpreted as a positive activity effect. Second, our finding of a fatigue-reducing association of activity on the between-person level could be due to the fact that regular activity leads to less overall fatigue, as has been shown in intervention studies (e.g., Puetz et al., 2006), possibly attributable to the higher fitness levels of regular exercisers. Consequently, these contrasting associations impressively demonstrate that effects have to be disentangled at the within- and between-person levels in order to gain deeper insight into the nature of the activity-affect association.

Limitations and directions for future studies

This study has several limitations. First, inferences about a causal effect of activity in terms of enhancing affect cannot be derived from the present study. Its intensive longitudinal design allowed us to detect an activity-affect association within persons that ruled out stable individual differences as alternative explanations of the association. The study also established temporal order, with daytime activity predicting evening affect. This study provides evidence for the promise of future intervention studies in this age group; these studies could establish a causal effect of activity by experimentally increasing activity on specific days with adequate washout periods following these activity days and thus rule out time-varying alternative explanations of the within-person activity-affect association found in this study. Second, questions about the underlying mechanisms linking activity and affect within persons remain unanswered and were beyond the scope of the current study. The next step in this

research program is to study potential mechanisms for activity effects on affect in daily life, including psychological pathways (e.g., higher self-efficacy and self-esteem), physiological processes (e.g., lowered arousal, favorable hormonal changes), and social processes (e.g., social support and companionship) as well as the timing of these processes. Moreover, future studies should also take into account the physical and social context in which activity is performed and affect is assessed, as highlighted in previous studies (e.g., indoor vs. outdoor, alone vs. with others: Dunton, Liao, Intille, Huh, & Leventhal, 2015; leisure vs. non-leisure time: Kanning, 2013). Third, distributions of negative affect variables are skewed. Future research should use items that differentiate lower intensities of negative affect. Fourth, our sample showed an elevated mean level of activity (M = 59 min/day) compared to representative US and German adult samples (i.e., M = 32 min/day; Troiano et al., 2008; Lampert, Mensink, & Müters, 2012). Thus, our sample of young adults seems to be not representative, meaning that our findings may not generalize to other populations differing in age or socio-economic status. However, the age group at hand is highly relevant because of elevated negative affect during young adulthood (Stone et al., 2010).

Implications for health promotion

Based on the present findings, important implications for health promotion can be derived. First, more activity than usual over the course of a day is associated with less depressed and less angry evening affect as well as more vigor and more serenity in young adults. Thus, physical activity may be further emphasized as a health promotion strategy (WHO, 2006) for managing unpleasant and pleasant affects of varying activation levels. Meeting the daily activity recommendations for physical health can also boost mental health as measured by improved evening affect. Thus, health promotion programs related to increased activity should target young adults, who often experience increased levels of negative affect and lower levels of positive affect (Carstensen et al., 2011; Stone et al., 2010). This can easily be implemented by, for instance, supporting young adults' regular participation in community and university exercise programs. Furthermore, daily levels of physical activity can be increased via action planning (Sniehotta, Scholz, & Schwarzer, 2005) and self-regulation strategies (e.g., implementation intentions; Stadler, Oettingen, & Gollwitzer, 2009; monitoring and feedback; Prestwich, Conner, Hurling, Ayres, & Morris, 2016) that can be tailored to individual needs.

Conclusion

To our knowledge, this is the first study in everyday life with a young adult sample demonstrating that days with more activity than usual were associated with less negative evening affect and more positive evening affect. Results are based on objective assessments of physical activity and on time-stamped online measures of affect, thus extending previous research using self-reported physical activity or paper-and-pencil assessments of affect by presenting a more valid database (Kanning et al., 2013). In light of young adults' increased risk of experiencing negative affect and low levels of positive affect in everyday life, our findings that persons can potentially influence their affect with activity is highly encouraging. Consequently, increasing young adults' physical activity could represent an important component of health promotion programs related to affective well-being as well as long-term health and may be an easily accessible intervention.

References

American Heart Association (2016, July 27). *Recommendations for physical activity in adults*. Retrieved from: http://www.heart.org/HEARTORG/HealthyLiving/PhysicalActivity/FitnessBasics/American-Heart-Association-Recommendations-for-Physical-Activity-in-Adults_UCM_307976_Article.jsp

Carstensen, L. L., Turan, B., Scheibe, S., Ram, N., Ersner-Hershfield, H., Samanez-Larkin, G. R., . . . Nesselroade, J. R. (2011). Emotional experience improves with age: evidence based on over 10 years of experience sampling. *Psychology and Aging, 26*, 21–33. doi:10.1037/a0021285

Charles, S. T., Piazza, J. R., Mogle, J., Sliwinski, M. J., & Almeida, D. M. (2013). The wear and tear of daily stressors on mental health. *Psychological Science, 24*, 733–741. doi:10.1177/0956797612462222

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*, 357–364. doi:10.1249/MSS.0b013e3181ed61a3

Cohen, S., Doyle, W. J., Turner, R. B., Alper, C. M., & Skoner, D. P. (2003). Emotional style and susceptibility to the common cold. *Psychosomatic Medicine, 65*, 652–657. doi:10.1097/01.PSY.0000077508.57784.

Conn, V. S. (2010). Depressive symptom outcomes of physical activity interventions: meta-analysis findings. *Annals of Behavioral Medicine, 39*, 128–138. doi:10.1007/s12160-010-9172-x

Cranford, J. A., Shrout, P. E., Iida, M., Rafaeli, E., Yip, T., & Bolger, N. (2006). A procedure for evaluating sensitivity to within-person change: Can mood measures in diary studies detect change reliably? *Personality and Social Psychology Bulletin, 32*, 917–929. doi:10.1177/0146167206287721

Diener, E., & Chan, M. Y. (2011). Happy people live longer: Subjective well-being contributes to health and longevity. *Applied Psychology: Health and Well-Being, 3*, 1–43. doi:10.1111/j.1758-0854.2010.01045.x

Dunn, A. L., Trivedi, M. H., & O'Neal, H. A. (2001). Physical activity dose-response effects on outcomes of depression and anxiety. *Medicine & Science in Sports & Exercise, 33*, 587–597. Retrieved from http://www.acsm.org/public-information/acsm-journals/medicine-science-in-sports-exercise

Dunton, G. F., Liao, Y., Intille, S., Huh, J., & Leventhal, A. (2015). Momentary assessment of contextual influences on affective response during physical activity. *Health Psychology, 34*(12), 1145–1153.

Eid, M., Diener, E., Eid, M., & Diener, E. (1999). Intraindividual variability in affect: Reliability, validity, and personality correlates. *Journal of Personality and Social Psychology, 76*, 662–676. doi:10.1037/0022-3514.76.4.662

European Working Group (2008, October 10). *EU-Leitlinien für körperliche Aktivität [European guidelines for physical activity]*. Retrieved from: http://ec.europa.eu/sport/library/policy_documents/eu-physical-activity-guidelines-2008_de.pdf

Eyre, H., & Baune, B. T. (2012). Neuroplastic changes in depression: a role for the immune system. *Psychoneuroendocrinology, 37*, 1397–1416. doi:10.1016/j.psyneuen.2012.03.019

Fahrenberg, J., Myrtek, M., Pawlik, K., & Perrez, M. (2007). Ambulatory assessment - Monitoring behavior in daily life settings. *European Journal of Psychological Assessment, 23*, 206–213. doi:10.1027/1015-5759.23.4.206

Flueckiger, L., Lieb, R., Meyer, A. H., Witthauer, C., & Mata, J. (2016). The importance of physical activity and sleep for affect on stressful days: Two intensive longitudinal studies. *Emotion, 16*, 488–497. doi:10.1037/emo0000143

Fortier, M. S., Guerin, E., Williams, T., & Strachan, S. (2015). Should I exercise or sleep to feel better?: A daily analysis with physically active working mothers. *Mental Health and Physical Activity, 8,* 56–61. doi:10.1016/j.mhpa.2015.03.001

Frijda, N.H. (2009). Mood. In D. Sander & K.R. Scherer (Eds.), *The Oxford companion to emotion and the affective sciences* (pp. 258–259). New York: Oxford University Press.

Gawrilow, C., Stadler, G., Langguth, N., Naumann, A., & Boeck, A. (2016). Physical activity, affect, and cognition in children with symptoms of ADHD. *Journal of Attention Disorders, 20*, 151–162. doi:10.1177/1087054713493318

Giacobbi, P. R., Hausenblas, H. A., & Frye, N. (2005). A naturalistic assessment of the relationship between personality, daily life events, leisure-time exercise, and mood. *Psychology of Sport and Exercise, 6*, 67–81. doi:10.1016/j.psychsport.2003.10.009

Hamaker, E. L. (2012). Why researchers should think within-person: A paradigmatic rationale. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 43–61). New York: Guilford Press.

Hautzinger, M., Bailer, M., Hofmeister, D., & Keller, F. (2012). *Allgemeine Depressionsskala (ADS) (2. Aufl.)[Center for Epidemiological Studies Depression Scale, CES-D]*. Göttingen: Hogrefe.

Hyde, A. L., Conroy, D. E., Pincus, A. L., & Ram, N. (2011). Unpacking the feel good effect of free-time physical activity: between-and within-person associations with pleasant-activated feeling states. *Journal of Sport & Exercise Psychology, 33*(6), 884–902.

Kanning, M. (2013). Using objective, real-time measures to investigate the effect of actual physical activity on affective states in everyday life differentiating the contexts of working and leisure time in a sample with students. *Frontiers in Psychology, 3*, 602. doi:10.3389/fpsyg.2012.00602

Kanning, M. K., Ebner-Priemer, U. W., & Schlicht, W. M. (2013). How to investigate within-subject associations between physical activity and momentary affective states in everyday life: A position statement based on a literature overview. *Frontiers in Psychology, 4*, 187. doi:10.3389/fpsyg.2013.00187

Kanning, M., Ebner-Priemer, U., & Schlicht, W. (2015). Using activity triggered e-diaries to reveal the associations between physical activity and affective states in older adult's daily living. *The International Journal of Behavioral Nutrition And Physical Activity, 12*, 111. doi:10.1186/s12966-015-0272-7

Kanning, M., & Schlicht, W. (2010). Be active and become happy: An ecological momentary assessment of physical activity and mood. *Journal of Sport & Exercise Psychology, 32*, 253–261. Retrieved from http://journals.humankinetics.com/jsep

Kiecolt-Glaser, J. K., McGuire, L., Robles, T. F., & Glaser, R. (2002). Emotions, morbidity, and mortality: New perspectives from psychoneuroimmunology. *Annual Review of Psychology, 53*, 83–107. doi:10.1146/annurev.psych.53.100901.135217

Kredlow, M. A., Capozzoli, M. C., Hearon, B. A., Calkins, A. W., & Otto, M. W. (2015). The effects of physical activity on sleep: a meta-analytic review. *Journal of Behavioral Medicine, 38*, 427–449. doi:10.1007/s10865-015-9617-6

Kühnhausen, J., Leonhardt, A., Dirk, J., & Schmiedek, F. (2013). Physical activity and affect in elementary school children's daily lives. *Frontiers in Psychology, 4*, 456. doi:10.3389/fpsyg.2013.00456

Lampert, T., Mensink, G. B. M., & Muters, S. (2012). Körperlich-sportliche Aktivität bei Erwachsenen in Deutschland. Ergebnisse der Studie "Gesundheit in Deutschland aktuell 2009" [Physical and sporting activity among adults in Germany. Results from the "German Health Update 2009" survey]. *Bundesgesundheitsblatt, 55*(1), 102–110. doi:10.1007/s00103-011-1401-3

Langguth, N., Schmid, J., Gawrilow, C., & Stadler, G. (2016). Within-person link between depressed affect and moderate-to-vigorous physical activity in adolescence: An intensive longitudinal approach. *Applied Psychology: Health and Well-Being, 8*, 44–63. doi:10.1111/aphw.12061

Lawlor, D. A., & Hopker, S. W. (2001). The effectiveness of exercise as an intervention in the management of depression: Systematic review and meta-regression analysis of randomised controlled trials. *British Medical Journal, 322*, 763–767. doi:10.2307/25466602

Lehnert, K., Sudeck, G., & Conzelmann, A. (2012). Subjective well-being and exercise in the second half of life: a critical review of theoretical approaches. *European Review of Aging and Physical Activity, 9*, 87–102. doi:10.1007/s11556-012-0095-3

Liao, Y., Shonkoff, E. T., & Dunton, G. F. (2015). The acute relationships between affect, physical feeling states, and physical activity in daily life: A review of current evidence. *Frontiers in Psychology, 6*, 1975. doi:10.3389/fpsyg.2015.01975

Maher, J. P., Doerksen, S. E., Elavsky, S., Hyde, A. L., Pincus, A. L., Ram, N., & Conroy, D. E. (2013). A daily analysis of physical activity and satisfaction with life in emerging adults. *Health Psychology, 32*, 647–656. doi:10.1037/a0030129

Mammen, G., & Faulkner, G. (2013). Physical activity and the prevention of depression: a systematic review of prospective studies. *American Journal of Preventive Medicine, 45*, 649–657. doi:10.1016/j.amepre.2013.08.001

Mata, J., Thompson, R. J., Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Gotlib, I. H. (2012). Walk on the bright side: Physical activity and affect in major depressive disorder. *Journal of Abnormal Psychology, 121*, 297–308. doi:10.1037/a0023533

McMinn, D., Acharya, R., Rowe, D. A., Gray, S. R., & Allan, J. L. (2013). Measuring activity energy expenditure: Accuracy of the GT3X+ and Actiheart monitors. *International Journal of Exercise Science, 6*, 217–229. Retrieved from http://digitalcommons.wku.edu/ijes/vol6/iss3/5

McNair, D. M., Lorr, M., & Droppleman, L. F. (1992). *EdITS manual for the Profile of Mood States*. San Diego, CA: Educational and Industrial Testing Services.

Molenaar, P. C., & Campbell, C. G. (2009). The new person-specific paradigm in psychology. *Current Directions in Psychological Science, 18*, 112–117. doi:10.1111/j.1467-8721.2009.01619.x

Parfitt, G., Rose, E. A., & Markland, D. (2000). The effect of prescribed and preferred intensity exercise on psychological affect and the influence of baseline measures of affect. *Journal of Health Psychology, 5*, 231–240. doi:10.1177/135910530000500213

Pasco, J. A., Jacka, F. N., Williams, L. J., Brennan, S. L., Leslie, E., & Berk, M. (2011). Don't worry, be active: positive affect and habitual physical activity. *The Australian and New Zealand Journal of Psychiatry, 45*, 1047–1052. doi:10.3109/00048674.2011.621063

Poole, L., Steptoe, A., Wawrzyniak, A. J., Bostock, S., Mitchell, E. S., & Hamer, M. (2011). Associations of objectively measured physical activity with daily mood ratings and psychophysiological stress responses in women. *Psychophysiology, 48*, 1165–1172. doi:10.1111/j.1469-8986.2011.01184.x

Posner, J., Russel, J. A., & Peterson, B. A. (2005). The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology. *Development and Psychopathology, 17*, 715–734.

Prestwich, A., Conner, M., Hurling, R., Ayres, K., & Morris, B. (2016). An experimental test of control theory-based interventions for physical activity. *British Journal of Health Psychology.* doi:10.1111/bjhp.12198

Prince, S. A., Adamo, K. B., Hamel, M., Hardt, J., Connor Gorber, S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity, 5*, 56. doi:10.1186/1479-5868-5-56

Puetz, T. W., O'Connor, P. J., & Dishman, R. K. (2006). Effects of chronic exercise on feelings of energy and fatigue: A quantitative synthesis. *Psychological Bulletin, 132*, 866–876. doi:10.1037/0033-2909.132.6.866

Reed, J., & Buck, S. (2009). The effect of regular aerobic exercise on positive-activated affect: A meta-analysis. *Psychology of Sport and Exercise, 10,* 581–594. doi:10.1016/j.psychsport.2009.05.009

Reis, H. T. (2012). Why researchers should think 'real-world': A conceptual rationale. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 3–21). New York: Guilford Press.

Rimer, J., Dwan, K., Lawlor, D. A., Greig, C. A., McMurdo, M., Morley, W., & Mead, G. E. (2012). Exercise for depression. *The Cochrane Database of Systematic Reviews, 7,* CD004366. doi:10.1002/14651858.CD004366.pub5

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review, 110,* 145 –172.

Ryan, M. P. (2008). The antidepressant effects of physical activity: mediating self-esteem and self-efficacy mechanisms. *Psychology & Health, 23,* 279–307. doi:10.1080/14768320601185502

Sasaki, J. E., John, D., & Freedson, P. S. (2011). Validation and comparison of ActiGraph activity monitors. *Journal of Science and Medicine in Sport, 14,* 411–416. doi:10.1016/j.jsams.2011.04.003

Schwerdtfeger, A., Eberhardt, R., & Chmitorz, A. (2008). Gibt es einen Zusammenhang zwischen Bewegungsaktivität und psychischem Befinden im Alltag? [Is there a correlation between everyday-life physical activity and psychological well-being? A methodological study using ambulatory monitoring]. *Zeitschrift für Gesundheitspsychologie, 16,* 2–11. doi:10.1026/0943-8149.16.1.2

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

Shrout, P. E., & Lane, S. P. (2012). Psychometrics. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 302–320). New York: Guilford Press.

Singer, J. D., & Willett, J. B. (2003). *Applied longitudinal data analysis: Modeling change and event occurrence*. New York: Oxford University Press.

Sniehotta, F. F., Scholz, U., & Schwarzer, R. (2005). Bridging the intention-behaviour gap: Planning, self-efficacy, and action control in the adoption and maintenance of physical exercise. *Psychology & Health, 20,* 143–160. doi:10.1080/08870440512331317670

Stadler, G., Oettingen, G., & Gollwitzer, P. M. (2009). Physical Activity in Women: Effects of a self-regulation intervention. *American Journal of Preventive Medicine, 36*, 29–34. doi:10.1016/j.amepre.2008.09.021

Stavrakakis, N., Booij, S. H., Roest, A. M., Jonge, P. de, Oldehinkel, A. J., & Bos, E. H. (2015). Temporal dynamics of physical activity and affect in depressed and nondepressed individuals. *Health Psychology, 34(Suppl.),* 1268–1277. doi:10.1037/hea0000303

Stone, A. A., Schwartz, J. E., Broderick, J. E., & Deaton, A. (2010). A snapshot of the age distribution of psychological well-being in the United States. *Proceedings of the National Academy of Sciences of the United States of America, 107*, 9985–9990. doi:10.1073/pnas.1003744107

Troiano, R. P., Berrigan, D., Dodd, K. W., Mâsse, L. C., Tilert, T., & McDowell, M. (2008). Physical activity in the United States measured by accelerometer. *Medicine & Science in Sports & Exercise, 40*(1), 181–188. doi:10.1249/mss.0b013e31815a51b3

Wichers, M., Peeters, F., Rutten, B. P. F., Jacobs, N., Derom, C., Thiery, E., . . . van Os, J. (2012). A Time-Lagged Momentary Assessment Study on Daily Life Physical Activity and Affect. *Health Psychology, 31*, 135–144. doi:10.1037/a0025688

World Health Organization. (2006). *Global database on body mass index*. Geneva: WHO.

World Health Organization. (2010). *Global recommendations on physical activity for health*. Geneva: WHO.

B. Manuscript 2: Review of Ambulatory Assessment Studies in School

Bugl, P., Schmid, J. & Gawrilow, C. (2015). Ambulantes Assessment in der Schule: Den schulischen Alltag erfahrbar machen [Ambulatory assessment in school: Discovering daily school life]. *Lernen und Lernstörungen, 4,* 261–268. doi:10.1024/2235-0977/a000115

FOKUS ANWENDUNG

Ambulantes Assessment in der Schule: Den schulischen Alltag erfahrbar machen

Petra Bugl, Diplom Psychologin, Doktorandin der Graduiertenschule LEAD an der Universität Tübingen seit Juni 2014. In ihrer Dissertation beschäftigt sie sich mit den Zusammenhängen von körperlicher Aktivität, Stimmung, Selbstregulation und Exekutiven Funktionen von Kindern und Erwachsenen. In Kooperation mit Johanna Schmid und Caterina Gawrilow führte sie eine ambulante Assessment-Studie im Alltag durch.

Dr. Johanna Schmid, Diplom Psychologin, Wissenschaftliche Mitarbeiterin am Arbeitsbereich Schulpsychologie und assoziiertes Mitglied der Graduiertenschule LEAD an der Universität Tübingen seit Oktober 2013. Ihre Forschungsschwerpunkte sind Lern- und Leistungsstörungen, Emotionsregulation, Selbstregulation und Exekutive Funktionen im (Schul-)Alltag.

Prof. Dr. Caterina Gawrilow, Professorin und Leiterin des Arbeitsbereichs Schulpsychologie an der Universität Tübingen seit April 2013 und assoziierte Wissenschaftlerin der Graduiertenschule LEAD und des DIPF Frankfurt. Ihre Forschungsschwerpunkte sind Lern-, Verhaltens- und Leistungsstörungen und Aspekte der Selbstregulation. Zuvor war sie Juniorprofessorin für Grundlagen von Lern- und Leistungsstörungen am IDeA-Zentrum des DIPF und der Goethe-Universität Frankfurt.

Zusammenfassung

Der Alltag von Schülerinnen und Schülern ist geprägt von Schwankungen des Lernertrags und des Lerngeschehens. Ziel dieses Beitrags ist es, das ambulante Assessment als Methode vorzustellen, die Zugang zu kurzfristig ablaufenden Schwankungen psychischer und physischer Prozesse innerhalb von Schülerinnen und Schülern oder Lehrkräften bietet. Durch zeitlich eng aufeinanderfolgende wiederholte Messungen wird ein neuer Blick auf den Schulalltag möglich. Besonders hervorzuheben ist das Potenzial ambulanten Assessments, Lernprozesse im Kontext eingebettet aus einer intraindividuellen Perspektive heraus zu betrachten. Erste empirische Evidenzen zu Schwankungen des Lerngeschehens als Bedingungen der schulischen Leistung verdeutlichen die Relevanz und den Nutzen ambulanten Assessments. Für eine Anwendung im Klassenzimmer sprechen viele Vorteile. Die konkrete Umsetzung bleibt herausfordernd und verlangt eine Kooperation zwischen Wissenschaft und Praxis. Zukünftige Studien im Schulkontext sind für alle Beteiligten gewinnbringend.

EINLEITUNG

Tag 1: Lea sitzt im Matheunterricht. Sie sollte eigentlich Testaufgaben lösen, aber beobachtet stattdessen die Schüler im Pausenhof. Sie möchte sich auch gerne bewegen. Als die Zeit um ist, stellt Lea mit Erschrecken fest, dass sie einige Aufgaben nicht bearbeitet hat.

Tag 2: Knapp eine Woche später schreibt Lea eine Mathearbeit. Heute ist ein guter Tag: Sie ist mit dem Fahrrad zur Schule geradelt und fühlt sich fit. Sie ist konzentriert und bearbeitet alle Aufgaben.

Externe Faktoren, wie die Situation, der Kontext, die Tageszeit, das Verhalten anderer Menschen, aber auch interne Faktoren, wie eigene Einstellungen, Erwartungen und Erfahrungen, bestimmen unser aktuelles Erleben und Handeln. Das vorangestellte Fallbeispiel der Schülerin Lea soll dies veranschaulichen. Ihre Mathematikleistung schwankt nicht nur aufgrund ihres Wissensstands, sondern auch aufgrund aktueller Erlebnisse und ihrer Aufmerksamkeitsleistung. Diese Schwankungen basieren auf psychischen und physischen Prozessen innerhalb von Personen, die sich zeit- und situationsabhängig verändern. Zumeist bleiben diese kurzfristigen Prozesse unbeobachtet – für die Person selbst und ihre Umgebung. Lern- und Leistungsschwankungen sind bei vielen Schülern zu beobachten und bilden nicht nur eine mögliche Symptomatik von Lern- und Verhaltensproblemen. Eine punktuelle Abfrage der Mathematikleistung liefert lediglich eine Momentaufnahme, die durch unterschiedliche Faktoren und Prozesse in einer spezifischen Situation x Zeit - Kombination beeinflusst wird. Der häufig in Forschung und Praxis vorgenommene reine Vergleich einzelner Messergebnisse zwischen Personen setzt einen anderen Fokus als die Sichtweise auf den Vergleich von Prozessen innerhalb einer Person. Ein Vergleich zwischen Personen beantwortet die Frage, ob Lea in beiden Mathetests eine bessere Note als ihr Nebensitzer bekommt. Jedoch gibt dies keinen Hinweis auf die Schwankungen von Lernprozessen einzelner Schülerinnen und Schüler und lässt somit außer Acht, ob Leas Leistung an Tag 1 schlechter oder an Tag 2 besser als für sie selbst üblich war.

Im schulischen Kontext sind Lernprozesse innerhalb von Personen besonders bedeutsam: sie können kurzfristig das Lernpotenzial beeinflussen und tragen dadurch längerfristig zum Bildungserfolg der Schülerinnen und Schüler bei. Eine diagnostische Analyse individueller Schwankungen von Lernprozessen kann wiederum der frühzeitigen personenspezifischen Förderung dienen.

Um Lernprozesse innerhalb von Personen zu untersuchen, eignet sich die Methode des *ambulanten Assessments*. Das ambulante Assessment kann als Oberbegriff für

Forschungsmethoden betrachtet werden, die emotionale, behaviorale und kognitive, physische oder Umwelt-Zustände innerhalb von Personen *ambulant*, d. h. in ihrem natürlichen Kontext und in Echtzeit, erfassen (*Society for Ambulatory Assessment*). Ziel des vorliegenden Beitrags ist es, das ambulante Assessment als Methode mit Anwendungspotenzial im schulischen Kontext vorzustellen. Dazu werden vorliegende Forschungsbefunde sowie Herausforderungen und Potenziale für die Forschung und Praxis berichtet, die mit der Anwendung ambulanten Assessments einhergehen.

Definition des ambulanten Assessments

Ambulantes Assessment zielt darauf ab, psychische und physische Zustände im alltäglichen Leben gemäß einer festgelegten Fragestellung und Messstrategie zu untersuchen (Fahrenberg, 1996, S. 2). Es ist charakterisiert durch folgende Aspekte der Messung:

* Gegenstand: emotionale, behaviorale, kognitive, physische oder Umwelt-Zustände

* Verfahren: subjektive oder objektive Verfahren unter Beachtung psychologischer Gütekriterien

* Umsetzung: Papier-und-Bleistift oder technische Geräte, wie Computer, portable Geräte, etc.

* Ablauf: zeitlich eng aufeinanderfolgende wiederholte Messungen derselben Person

* Setting: im natürlichen Kontext und in Echtzeit

Als Messverfahren des ambulanten Assessments können subjektive Methoden des Selbstberichts (z. B. Tagebücher) und objektive Verfahren (z. B. Bewegungsmesser) eingesetzt werden. Um interpretierbare Messwerte zu erhalten, sollen die verwendeten Verfahren die Gütekriterien einer wissenschaftlichen Messung erfüllen (Kubinger, 2009). Typischer Ablauf (Design) einer ambulanten Assessment-Studie ist ein sogenannter *intensiver Längsschnitt*. Charakteristisch hierfür ist eine dichte Datenerhebung innerhalb einer relativ kurzen Zeitspanne (Bolger & Laurenceau, 2013), wie im Schulalltag stattfindende, mehrmals täglich realisierte Messungen (z. B. Könen et al., 2015). Zeitraum und Erhebungsplan des ambulanten Assessments werden abhängig von der Fragestellung und den interessierenden Schwankungen festgelegt (Fahrenberg et al., 2007).

Vorteile des ambulanten Assessments für die schulpsychologische Forschung

Ambulantes Assessment ist eine bedeutende Methode der empirischen Psychologie: es ist alltagsnah, gibt die Möglichkeit zur Untersuchung intraindividueller Prozesse und ist sensitiv für multimodale Kontextfaktoren.

Alltagsnähe – ökologische Validität

Ökologische Validität beschreibt die Übereinstimmung der Studienbedingungen mit den Bedingungen im echten Leben. Nur bei hoher ökologischer Validität von Studien können deren Ergebnisse auf reale Kontexte übertragen werden. Ambulante Assessment-Studien sind durch eine hohe ökologische Validität gekennzeichnet, da menschliches Erleben und Verhalten direkt in natürlicher Umgebung erfasst wird (Fahrenberg, Myrtek, Pawlik & Perrez, 2007). Zum anderen werden durch die Erfassung im Alltagskontext und in Echtzeit potenzielle Verzerrungen retrospektiver Befragungen vermieden. Eine andere Art von Informationen wird zugänglich, die das Erleben und Verhalten als Momentaufnahme zum Forschungsgegenstand macht. Erinnert sich Lea beispielsweise an ihre Stimmung während des Mathetests an Tag 1, so berichtet sie retrospektiv nach einer Woche wahrscheinlich eine andere Stimmung, als sie es auf Basis einer täglichen Befragung in der Situation getan hätte, denn eine retrospektive Stimmungsangabe wird auch von der aktuellen Stimmung zum Messzeitpunkt beeinflusst (Brose, Lindenberger & Schmiedek, 2013).

Intraindividuelle Perspektive

Ein zweiter Vorteil ambulanter Assessments stellt die hiermit ermöglichte Untersuchung von Phänomenen aus einer *intraindividuellen Perspektive* (*within-persons*) dar (Hamaker, 2012). Viele psychologische Erkenntnisse basieren auf Studien mit querschnittlichen Forschungsdesigns, in denen eine große Anzahl von Personen zu einem einzigen Zeitpunkt untersucht wird. In der Regel werden hierbei über alle Personen der Stichprobe hinweg aggregierte Kennwerte berechnet und es erfolgen Vergleiche zwischen Personen (*interindividuelle Ebene, between-persons*). Zum Beispiel wurde auf Ebene zwischen Personen ein Zusammenhang zwischen der Lesegeschwindigkeit und dem Leseverständnis gefunden (Wallot, O'Brien, Haussmann, Kloos & Lyby, 2014): Schüler, die schneller lesen konnten als andere, zeigten auch ein besseres Textverständnis. Allerdings ist

der berichtete Zusammenhang nicht zwangsläufig auf Zusammenhänge innerhalb von Personen übertragbar. Würden den Schülern mehrmals innerhalb kurzer Zeitabstände (z. B. mehrfach pro Schultag) wiederholt Leseaufgaben vorgelegt, so wäre durchaus plausibel, dass ein Schüler zu Zeitpunkten, zu denen er schneller als üblich liest, ein schlechteres Verständnis als für ihn üblich zeigt (z. B. aufgrund begrenzter Verarbeitungskapazität). Der Zusammenhang von Lesegeschwindigkeit und -verständnis wäre folglich nur auf interindividueller Ebene linear positiv und könnte auf intraindividueller Ebene hingegen linear negativ verlaufen, wie in Abbildung 1 hypothetisch veranschaulicht. Ein direkter Transfer der Evidenz von der inter- auf die intraindividuelle Ebene ist meist nicht möglich (Molenaar & Campbell, 2009). *(Hier Abbildung 1 einfügen)*

Des Weiteren ermöglicht ambulantes Assessment die Erfassung psychologischer und physiologischer Konstrukte jenseits von stabilen Merkmalen (*Traits*) als veränderliche Zustände (*States*). Alltagsberichte weisen darauf hin, dass menschliches Erleben und Verhalten bedeutsame intraindividuelle Variabilität aufweist, wie beispielsweise Leas tägliche Aufmerksamkeitsschwankungen. Fokus ambulanten Assessments sind Schwankungen und Prozesse in einem zeitlich engen Rahmen (z. B. von Tag zu Tag, innerhalb eines Tages; Bolger & Laurenceau, 2013). Ansätze auf intra- und interindividueller Ebene ergänzen sich (Tabelle 1): Beide Perspektiven sind nötig für eine umfassende Charakterisierung menschlichen Erlebens und Verhaltens (Schmitz, 2006). *(Hier Tabelle 1 einfügen)*

Sensitivität für multimodale Kontextfaktoren

Eine weitere Besonderheit ambulanten Assessments ist zudem die *Sensitivität für multimodale Kontextfaktoren* emotionaler, behavioraler, kognitiver und physischer Zustände in situ und über die Zeit hinweg zu untersuchen (Ebner-Priemer & Trull, 2009). Zudem können introspektiv nicht zugängliche Prozesse durch die ambulante Erfassung kognitiver, behavioraler, physischer oder Umwelt-Zustände beobachtbar werden. Interessant wäre beispielsweise, ob Leas Aufmerksamkeitsleistung differentiell mit ihrer physischen Aktivierung (z. B. messbar über die Herzrate) zusammenhängt.

Die Messung kontextspezifischer Vorläufer und Folgen von Schwankungen kann darüber hinaus zur Ableitung von Interventionen beitragen. Beispielsweise könnte anhand eines ambulanten Assessments geprüft werden, ob Leas schwankende Aufmerksamkeitsleistung auf ihre (Un-)Ausgeglichenheit durch (mangelnde) Bewegung

zurückzuführen ist. Die direkte Einbettung des ambulanten Assessments in den Kontext ermöglicht somit, alltagswirksame Faktoren in die Konzeption psychologischer Theorien einzubeziehen.

ANWENDUNG DES AMBULANTEN ASSESSMENTS IM SCHULISCHEN KONTEXT

Lernprozesse anzuregen, um erwünschte Lernziele zu erreichen, ist ein zentrales Anliegen des schulischen Unterrichts. Der *Lernertrag* spiegelt sich in (über-)fachlichen Kompetenzen und erzieherischen Wirkungen der Schule wider. Zudem ist der Lernertrag multifaktoriell bedingt durch vorausgehende *Lernprozesse*, die aus dem wechselseitigen Einfluss des Angebots in Form des Unterrichts durch die Lehrkraft und insbesondere der Nutzung dieses Angebots durch die Schülerinnen und Schüler resultieren (Helmke & Schrader, 2015). Ambulantes Assessment kann zur diagnostischen Beschreibung von Lernprozessen in Form von emotionalen, behavioralen, kognitiven, physischen und Umwelt-Zuständen der Lehrkräfte (Angebot) und der Schülerinnen und Schüler (Nutzung) dienen und somit indirekt den Lernertrag beschreiben. Im Vordergrund steht dabei der ablaufende Prozess von einem Zustand geringen Wissens und weniger Kompetenzen hin zu Zuständen mit größerem Wissen und mehr Kompetenzen (Schmitz, 2006). Ambulantes Assessment bietet potenziell viele Möglichkeiten, den resultierenden Lernertrag durch Lernprozesse zu beschreiben.

Beschreibung des Lernertrags

Ambulantes Assessment im Schulkontext unterscheidet sich von der *Lernverlaufsdiagnostik* vor allem aufgrund seiner spezifischen Perspektive auf den Lernprozess (Hasselhorn, Schneider & Trautwein, 2014). Fokus ambulanter Assessment-Studien sind tägliche und innertägliche Schwankungen emotionaler, kognitiver, behavioraler, physischer und Umwelt-Zustände, die den Lernertrag beeinflussen. Lernstandsschwankungen sollen hierbei durch zugrundeliegende Lernprozesse sichtbar und erklärbar werden. Ambulantes Assessment nutzt somit einen anderen Weg für dasselbe Ziel, Schwankungen von Lernerträgen zu beschreiben. In der Lernverlaufsdiagnostik hingegen stehen Veränderungen des Lernertrags erfasst anhand von Schulleistungstests oder

curriculumsbasierten Maßen über längere Zeitintervalle im Fokus. Beispielsweise kann der Entwicklungsverlauf der Rechtschreibkompetenz von Grundschülern durch eine wöchentliche Testung mit gleich schwierigen Aufgaben über ein halbes Schuljahr abgebildet werden (Strathmann, Klauer & Greisbach, 2010). Im Gegensatz dazu werden mit ambulantem Assessment kurzfristigere Schwankungen innerhalb eines Tages oder von Tag zu Tag untersucht.

Warum ist es sinnvoll, zeitlich kurzfristig Veränderungen des Lernprozesses im schulischen Kontext zu untersuchen? Alltagsberichte spiegeln schwankende Lernerträge in Form von Schulleistungen in zeitlich kurzen Abständen wider. Leas Matheleistung schwankt beispielsweise innerhalb einer Woche beträchtlich. Erste Studien mit erwachsenen Probanden verdeutlichen die Bedeutsamkeit kognitiver Schwankungen innerhalb von Personen. Salthouse und Berish (2005) untersuchten Schwankungen in der Wahl-Reaktionszeit, die mit kognitiven Indikatoren, wie der Verarbeitungsgeschwindigkeit, assoziiert ist. Mittels klingelnder Palmtop-Geräte wurden die Teilnehmer zur Bearbeitung von 105 Aufgaben - zufällig über sieben Tage verteilt - aufgefordert. Schwankungen in der Reaktionszeit innerhalb von Personen von einer Messung zur anderen waren genau so groß wie die über alle Messungen aggregierten mittleren Reaktionszeit-Unterschiede zwischen Personen. Abhängig vom Zeitpunkt der Messung erreichte demnach dieselbe Person die gleiche Reaktionszeit wie der im Durchschnitt schnellste oder langsamste Teilnehmer der gesamten Stichprobe. Ambulantes Assessment ist folglich notwendig, um die kognitive Leistung einer Person umfassend abzubilden und situationsspezifische Faktoren zur Erklärung kognitiver Schwankungen auf intraindividueller Ebene zu identifizieren.

Kenntnisse über kurzfristige Schwankungen können wichtige Hinweise für die Interpretation von punktuellen Leistungsmessungen liefern. Eine einmalige Mathetestung kann somit – durch Kenntnis der individualtypischen Aufmerksamkeitsschwankung – differenziell interpretiert werden. Wissen wir beispielsweise durch ein ambulantes Assessment über mehrere Tage, dass Lea sich an Tagen, an denen sie bereits sportlich aktiv war (z. B. mit dem Fahrrad zur Schule geradelt ist), besonders gut konzentrieren kann, so könnten für sie optimale Testbedingungen geschaffen werden, um ihre bestmögliche Matheleistung zu erfassen. Ambulante Assessment-Studien im schulischen Kontext sind zentral, um kurzfristige Schwankungen von Lernprozessen sichtbar zu machen und somit Hinweise für das Zustandekommen des Lernertrags zu geben.

Beschreibung des Lernprozesses

Schwankungen von Zuständen der Schülerinnen und Schüler oder Lehrkräfte, die direkt mit dem Lernprozess zusammenhängen und den Lernertrag beeinflussen, sind Gegenstand pädagogisch-psychologischer Studien mit ambulantem Assessment. Exemplarisch werden empirische Evidenzen schwankender Lernprozesse zusammengefasst.

Die Leistung in einem Schultest (Lernertrag) wird wesentlich von basalen kognitiven Fähigkeiten, wie der Arbeitsgedächtnisleistung, beeinflusst. In der FLUX-Studie (Assessment of Cognitive Performance FLUctuations in the School ConteXt) wurden tägliche *Arbeitsgedächtnisschwankungen* im Schulkontext untersucht. Insgesamt 110 Grundschülerinnen und -schüler der 3. und 4. Klasse bearbeiteten drei Mal täglich an 31 aufeinanderfolgenden Tagen auf einem Smartphone präsentierte Arbeitsgedächtnisaufgaben (Könen, Dirk & Schmiedek, 2015). Neben der Beschreibung der Arbeitsgedächtnisschwankungen bestand ein weiteres Ziel in der Identifikation ihrer Prädiktoren und Konsequenzen. Deshalb sollten die Schüler zusätzlich Fragen zur Stimmung, Motivation und zum Schlafverhalten beantworten. Es ergaben sich bedeutsame intraindividuelle Schwankungen der Arbeitsgedächtnisleistung innerhalb eines Tages und von Tag zu Tag. Zusammenhänge systematischer Schwankungen wurden identifiziert und können zur Erklärung von Lern- und Leistungsschwankungen beitragen.

Schwankungen im selbstregulierten Lernverhalten untersuchten Schmitz und Wiese (1999) mithilfe täglich eingesetzter Fragebögen im Alltagskontext von Berufsschülern. Die teilnehmenden Schülerinnen und Schüler waren aufgefordert, über 14 Tage vor einer anstehenden Prüfung hinweg jeden Nachmittag Lerntagebücher zu ihrem aktuell ausgeübten Lernverhalten sowie zu motivationalen, affektiven und situationalen Faktoren zu beantworten. Zeitreihenanalysen zeigten signifikante Schwankungen des Lernverhaltens. Beispielsweise nahmen die tatsächliche und effektive Lernzeit kurz vor der Prüfung zu, allerdings stieg auch die Diskrepanz zwischen beiden an. Schüler lernten beim Herannahen der Prüfung also eher ineffektiv.

Zudem werden Lernprozesse von *emotionalen und motivationalen Schwankungen* beeinflusst (Schmitz & Wiese, 1999). Bestimmte Konstellationen affektiver und motivationaler Zustände sagten den Einsatz spezifischer Lernstrategien vorher: Zum Beispiel waren Lernsituationen mit geringer negativer Stimmung der Schüler und hoher intrinsischer Motivation mit dem vermehrten Einsatz weiterführender Lernstrategien (z. B. Literatur suchen) assoziiert.

Das Ausmaß intraindividueller Stimmungsschwankungen kann weiterhin als Gesundheitsindikator dienen und somit Grundvoraussetzungen des Lernens beeinflussen. Ein ambulantes Assessment der Stimmung, realisiert durch 5-7 zufällige Abfragen pro Tag über eine Woche hinweg, zeigte einen Zusammenhang zwischen der Ausprägung intraindividueller Stimmungsschwankungen und dem Ausüben risikoreichen Gesundheitsverhaltens (Weinstein, Mermelstein, Shiffman & Flay, 2008). Jugendliche, deren negative Stimmung stark schwankte, gaben vermehrten Zigarettenkonsum an. Die Erfassung schwankender Stimmungszustände liefert also Informationen, die langfristig der Gesundheitsförderung von Schülern dienen können.

Schwankungen des Verhaltens hängen wiederum mit Stimmungsschwankungen zusammen und können somit ebenfalls den Lernprozess beeinflussen: Eine Studie mit 119 Grundschülerinnen und -schüler untersuchte Schwankungen der Bewegung mittels objektiver Bewegungsmesser und selbstberichteter Stimmung auf Smartphones (Dunton et al., 2014). Vor und nach moderat-intensiver Bewegung berichteten die Schüler mehr Energie. Darüber hinaus zeigten aktivere Schüler geringere Stimmungsschwankungen als weniger aktive Schüler. Folglich werden kurzfristige Schwankungen in Lernprozessen durch die genannten ambulanten Assessment-Studien zugänglich und dadurch auch Lernerträge auf eine neue Weise verstehbar.

Ambulantes Assessment als Intervention

Zusätzlich zur diagnostischen Beschreibung von Schwankungen kann ambulantes Assessment als Intervention zur Förderung von Lernprozessen genutzt werden, da die Selbstbeobachtung ambulant erfasster Zustände eine Verhaltensänderung beeinflussen kann. Beispielsweise ist das regelmäßige Ausfüllen standardisierter Lerntagebücher mit einer zunehmenden Lernqualität assoziiert (Schmitz & Wiese, 2006). Durch ambulantes Assessment kann weiterhin eine direkt im Kontext eingebettete Intervention umgesetzt werden (*Ecological Momentary Intervention*; Heron & Smith, 2010). Vorteilhaft ist dabei, dass adaptive Interventionen abhängig von ambulant erfassten Parametern ermöglicht werden. Zum Beispiel könnte ein Schüler bei ambulant erfasster geringer Lernmotivation eine individualisierte Nachricht auf dem Smartphone erhalten, um vorab gelernte Selbstregulationsstrategien gezielt einzusetzen (Gawrilow, Morgenroth, Schultz, Oettingen & Gollwitzer, 2013).

Potenziale ambulanten Assessments im Klassenzimmer

Ambulantes Assessment birgt das Potenzial für Diagnostik im Klassenraum und bietet dafür neben den bereits genannten Vorteilen spezifische Vorzüge. Durch den Fokus auf kurzfristige Veränderungen beim einzelnen Schüler wird die Individualität in besonderem Maße beachtet. Um den aktuellen Zustand eines Schülers zu beurteilen, kann ein vorheriger Zustand desselben Schülers als Referenz dienen (*individuelle Bezugsnorm;* Rheinberg, 2001). Entwicklungen von Schülern, die im sozialen Vergleich, beispielsweise auf Klassenebene, wenig auffallen, werden somit zugänglich. Ebenso unterstützt ambulantes Assessment im Schulkontext die Aufdeckung kurzfristiger Schwankungen, die mit positiven Lernerträgen einhergehen, so dass perspektivisch optimale Entwicklungen als kriteriale Referenzen etabliert und frühzeitige Interventionen möglich werden. Praktisch gesehen, können kurzfristige Veränderungen in Form von graphischen Verlaufskurven veranschaulicht werden. Ein ambulantes Assessment kann darüber hinaus einen differenzierten Ausgangspunkt für Beratungsgespräche mit Schülern, Eltern, (Beratungs-) Lehrkräften und/oder Schulpsychologen bieten. Die bei einem Beratungsfall üblicherweise durchgeführten standardisierten Tests außerhalb des regulären Unterrichts können durch Informationen des ambulanten Assessments im realen Schulkontext ergänzt werden.

Ein weiterer Vorteil ambulanten Assessments ist die einfache Implementierung im Regelunterricht. Mittels portabler Geräte, wie Smartphones oder Bewegungsmessern, können Messungen zeit- und situationsflexibel direkt im Unterricht durchgeführt werden. Die Handhabbarkeit wurde bereits in der Grundschule gezeigt (Könen et al., 2015). Aber auch ohne technische Geräte ist ambulantes Assessment im Klassenzimmer möglich, beispielsweise können Papierfragebögen genutzt werden. Gekoppelt mit einem Wecker, der die Aufforderung zum Ausfüllen des Fragebogens durch einen Ton angibt, ermöglichen auch diese eine zeit- und situationsabhängige oder -zufällige ambulante Messung.

Ambulantes Assessment reduziert Lernprozesse im Schulkontext nicht auf eine punktuelle Messung, sondern berücksichtigt die natürliche Schwankung des Lernprozesses, wie beispielsweise kognitive Schwankungen von Schülern (Könen et al., 2015). Dementsprechend könnte ein über tägliche Messungen aggregierter Kennwert ein valides Abbild für das tatsächlich vorhandene Lernpotenzial eines Schülers sein. Ambulantes Assessment schwankender Prozesse, die das Lerngeschehen beeinflussen, kann zur Herstellung einer optimalen Lernatmosphäre, aber auch zur Gesundheitsprävention der Schüler dienen. Schüler begegnen im Laufe ihrer Entwicklung wiederholt anfordernde

Übergänge im Bildungssystem (z. B. von der Grund- in die weiterführende Schule). Ambulantes Assessment kann die für ein Gelingen der Transition relevanten Prozesse greifbar und in einem zukünftigen Schritt förderbar machen.

Nicht zuletzt könnten im Zentrum eines ambulanten Assessments diagnostische Beschreibungen von Schwankungen der Lehrkraft stehen. Schwankungen in der Stimmung, Motivation und Lehrleistung der Lehrkraft können für die Lernprozesse ihrer Schüler sehr bedeutend sein. Die Gesundheitsprävention für Lehrkräfte kann zudem durch Ergebnisse ambulanten Assessments unterstützt werden.

HERAUSFORDERUNGEN DES AMBULANTEN ASSESSMENTS

Ambulantes Assessment zeichnet sich durch seine einzigartige Perspektive auf Prozesse innerhalb von Personen und seine Alltagsnähe aus. Allerdings stellen sich der Forschung und Anwendung auch einige Herausforderungen: Die Durchführung ambulanten Assessments setzt eine freiwillige Teilnahme und explizite Einwilligung der Schüler voraus. Die Einhaltung des Datenschutzes ist besonders im Hinblick auf die technologischen Weiterentwicklungen zu gewährleisten (Miller, 2012). Da Aufzeichnungen in unvorhersehbaren Situationen möglich sind, ist im Anschluss an ein ambulantes Assessment ein Aufklärungsgespräch mit den Teilnehmern wünschenswert (Fahrenberg et al., 2007).

Zur Realisierung ambulanten Assessments sind spezifische methodische Kenntnisse und zeitliche Investitionen notwendig, u. a. in Bezug auf den Ablauf einer ambulanten Assessment-Studie, die Auswahl geeigneter Messverfahren, die Aufbereitung und Auswertung der gemessenen Daten (Mehl & Conner, 2012). Beispielsweise sind änderungssensitive Messverfahren nötig, um kurzfristig ablaufende Schwankungen abzubilden (z. B. *Reliability of Change*; Shrout & Lane, 2012) sowie spezielle statistische Verfahren, um die Variation innerhalb von Personen zu analysieren (z. B. Mehrebenenmodelle; Bryk & Raudenbush, 1987). Die wiederholte Darbietung von Aufgaben erfordert zudem die Kontrolle von Trainingseffekten. Eine Anwendung ambulanten Assessments durch Lehrkräfte benötigt demnach eine wissenschaftliche Begleitung. Häufig diskutiert wird auch, inwieweit ein ambulantes Assessment intern valide ist, d. h. inwieweit das Messergebnis tatsächlich das abbildet, was gemessen werden soll. Ambulantes Assessment erfolgt meist ohne direkte Überwachung durch die Versuchsleiter, so dass die interne Validität nicht im selben Maße wie in Laborstudien kontrollierbar ist. Zudem sollte die Reaktivität ambulanten Assessments, d. h. der Reaktionen durch die

Messung selbst, überprüft werden. Ambulantes Assessment erfordert Schüler oder Lehrkräfte innerhalb eines Zeitraumes häufig wiederholt mit Messsituationen zu konfrontieren. Ein Kosten-Nutzen-Abgleich der Zumutungen an die Probanden und des zu erwartenden Erkenntnisgewinnes durch ambulantes Assessment scheint sinnvoll und kann zusätzlich im Rahmen einer Prüfung auf ethische Unbedenklichkeit erfolgen.

FAZIT

Eine breitflächige Umsetzung ambulanter Assessment-Studien in der Schule hat begonnen. Besonders vorteilhaft sind die alltagsnahe, multimodale Erfassung durch ambulantes Assessment und die Möglichkeit einer intraindividuellen Perspektive auf Schülerinnen und Schüler sowie Lehrkräfte im Schulkontext. Erste Evidenzen weisen auf die Relevanz von Schwankungen in Lernprozessen hin. Ausblickend sind weitere Messverfahren zum ambulanten Assessment für Forschung und Praxis zu entwickeln. Zukünftige ambulante Assessment-Studien im Schulkontext erscheinen sehr gewinnbringend für teilnehmende Schüler, Eltern, Lehrkräfte und Schulpsychologen.

Literatur

Bolger, N. & Laurenceau, J.-P. (2013). *Intensive longitudinal methods: An introduction to diary and experience sampling research*. New York, London: Guilford Press.

Brose, A., Lindenberger, U. & Schmiedek, F. (2013). Affective states contribute to trait reports of affective well-being. *Emotion, 13*, 940 - 948.

Bryk, A. S. & Raudenbush, S. W. (1987). Application of hierarchical linear models to assessing change. *Psychological Bulletin, 101*, 147 - 158.

Dunton, G. F., Huh, J., Leventhal, A. M., Riggs, N., Hedeker, D., Spruijt-Metz, D. & Pentz, M. A. (2014). Momentary assessment of affect, physical feeling states, and physical activity in children. *Health Psychology, 33* (3), 255 - 263.

Ebner-Priemer, U. W. & Trull, T. J. (2009). Ambulatory Assessment: An Innovative and Promising Approach for Clinical Psychology. *European Psychologist, 14* (2), 109 - 119.

Fahrenberg, J. (1996). Ambulatory assessment: Issues and perspectives. In J. Fahrenberg & M. Myrtek (Eds.), *Ambulatory assessment: Computer-assisted psychological and psychophysiological methods in monitoring and field studies* (pp. 3 - 20). Seattle, WA: Hogrefe & Huber.

Fahrenberg, J., Myrtek, M., Pawlik, K. & Perrez, M. (2007). Ambulantes Assessment - Verhalten im Alltagskontext erfassen. *Psychologische Rundschau, 58* (1), 12 - 23.

Gawrilow, C., Morgenroth, K., Schultz, R., Oettingen, G. & Gollwitzer, P. M. (2013). Mental contrasting with implementation intentions enhances self-regulation of goal pursuit in schoolchildren at risk for ADHD. *Motivation and Emotion, 37* (1), 134 - 145.

Hamaker, E. L. (2012). Why researchers should think within-person: a paradigmatic rationale. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 43 - 61). New York: Guilford Press.

Hasselhorn, M., Schneider, W. & Trautwein, U. (Eds.). (2014). *Tests und Trends: Vol. 12. Lernverlaufsdiagnostik* (1. Aufl.). Göttingen: Hogrefe Verlag.

Helmke, A. & Schrader, F. (2015). Angebots-Nutzungs-Modell der Wirkfaktoren akademischer Leistungen. In M. A. Wirtz (Hrsg.), *Dorsch – Lexikon der Psychologie*. Zugriff am 07.04.2015. Verfügbar unter https://portal.hogrefe.com/dorsch

Heron, K. E. & Smyth, J. M. (2010). Ecological momentary interventions: Incorporating mobile technology into psychosocial and health behaviour treatments. *British Journal of Health Psychology, 15* (1), 1 - 39.

Könen, T., Dirk, J. & Schmiedek, F. (2015). Cognitive benefits of last night's sleep: daily variations in children's sleep behavior are related to working memory fluctuations. *Journal of Child Psychology and Psychiatry, 56* (2), 171 - 182.

Kubinger, K. D. (2009). *Psychologische Diagnostik – Theorie und Praxis psychologischen Diagnostizierens* (2. Aufl.). Göttingen: Hogrefe.

Mehl, M. R. & Conner, T. S. (Eds.). (2012). *Handbook of research methods for studying daily life*. New York: Guilford Press.

Miller, G. (2012). The Smartphone Psychology Manifesto. *Perspectives on Psychological Science, 7* (3), 221 - 237.

Molenaar, P. C. & Campbell, C. G. (2009). The New Person-Specific Paradigm in Psychology. *Current Directions in Psychological Science, 18* (2), 112 - 117.

Salthouse, T. A. & Berish, D. E. (2005). Correlates of within-person (across-occasion) variability in reaction time. *Neuropsychology, 19* (1), 77 - 87.

Schmitz, B. (2006). Advantages of studying processes in educational research. *Learning and Instruction, 16* (5), 433 - 449.

Schmitz, B. & Wiese, B. S. (1999). Eine Prozessstudie selbstregulierten Lernverhaltens im Kontext aktueller affektiver und motivationaler Faktoren. *Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie, 31*, 157 - 170.

Schmitz, B. & Wiese, B. S. (2006). New Perspectives for the Evaluation of Training Sessions in Self- Regulated Learning: Time- Series Analyses of Diary Data. *Contemporary Educational Psychology, 31*, 64 - 96.

Society for Ambulatory Assessment. (n.d.). Zugriff am 01.04.2015. Verfügbar unter http://www.ambulatory-assessment.org

Shrout, P. E. & Lane, S. P. (2012). Psychometrics. In M. R. Mehl & T. S. Conner (Eds.), *Handbook of research methods for studying daily life* (pp. 302 - 320). New York: Guilford Press.

Strathmann, A. M., Klauer, K. J. & Greisbach, M. (2010). Lernverlaufsdiagnostik in Schulklassen. Dargestellt am Beispiel der Entwicklung der Rechtschreibkompetenz in der Grundschule. *Empirische Sonderpädagogik, 1*, 64 - 77.

Wallot, S., O'Brien, B. A., Haussmann, A., Kloos, H. & Lyby, M. S. (2014). The role of reading time complexity and reading speed in text comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40* (6), 1745 - 1765.

Weinstein, S. M., Mermelstein, R., Shiffman, S. & Flay, B. (2008). Mood variability and cigarette smoking escalation among adolescents. *Psychology of Addictive Behaviors, 22* (4), 504 - 513.

Tabelle 1

Ambulante Assessment- und Querschnitts-Studien im Vergleich

	Ambulante Assessment-Studien	***Querschnitts-Studien***
Messung	Zeitlich nahe wiederholte Messungen derselben Personen	Punktuelle Messung verschiedener Personen
Ebene	Intraindividuell (Within-Persons)	Interindividuell (Between-Persons)
Beschreibung	Prozesse	Diskreter Zustand
Konstrukte	Veränderliche Zustände (State)	Stabile Merkmale (Trait)
Analysefokus	Variation innerhalb von Personen, z. B. durch Mehrebenenmodelle	Variation zwischen Personen, z. B. durch Tests auf Gruppenunterschiede
Mögliche Fragestellungen	Schwankt die Aufmerksamkeitsleistung von Lea innerhalb eines Tages? Welche Kontextfaktoren können eine Schwankung erklären? Wie kann die Schwankung abgeschwächt werden?	Welche Matheleistung erzielt Lea im Vergleich zu ihrer Klasse? Welche Merkmale erklären den Leistungsunterschied? Wie kann der Leistungsunterschied abgeschwächt werden?

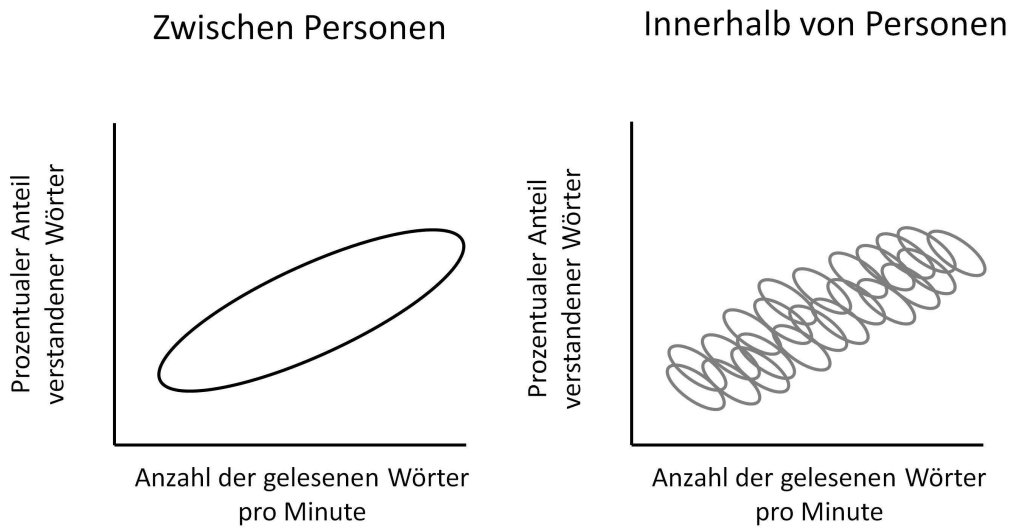

Abbildung 1. Zusammenhang zwischen Lesegeschwindigkeit und -verständnis auf Ebene zwischen Personen (links, Ellipse repräsentiert verschiedene Personen) und innerhalb von Personen (rechts, jede Ellipse repräsentiert eine Person; adaptiert von Hamaker, 2012, S. 44).

C. Manuscript 3: Physical Activity Intervention to Improve Young Children's Executive Functions

Haas, P., Cattarius, M., Meibohm, M., Schmid, J., Sudeck, G., Kelava, A., & Gawrilow, C. (2017). Improving young children's executive functions with physical activity: The role of motor coordination experiences. *Manuscript in preparation.*

Improving Young Children's Executive Functions with Physical Activity: The Role of Motor Coordination Experiences

Petra Haas[1]

Planned co-authors: Marcel Cattarius[2], ,Marie Meibohm[2], Johanna Schmid[1,2], Gorden Sudeck[1,3], Augustin Kelava[1,4], Caterina Gawrilow[1,2]

[1] LEAD Graduate School & Research Network
University of Tübingen
Gartenstr. 29
72074 Tübingen
Germany

[2] Institute of Psychology
Faculty of Science
University of Tübingen
Schleichstr. 4
72076 Tübingen
Germany

[3] Institute of Sports Science
Faculty of Economics and Social Sciences
University of Tübingen
Wächterstr. 67
72074 Tübingen
Germany

[4] Hector Research Institute of Education Sciences and Psychology
Faculty of Economics and Social Sciences
University of Tübingen
Europastr. 6
72072 Tübingen
Germany

Corresponding author: Petra Haas, petra.haas@uni-tuebingen.de

word count (text + references): 9,787 words

Abstract

Objective: Early executive functions are pivotal for future academic and social functioning. Physical activity has been shown to improve executive functions (i.e., cognitive aspects of self-regulation) in adults, while to date the effects in young children are unclear. The present study investigates the effectiveness of acute physical activity to improve subsequent executive functions in young children and also takes the moderating influence of motor coordination experiences into account.

Method: Hundred-three children (46% girls; age: *M* = 68.50 months, *SD* = 12.93) were randomly assigned to a physical activity or sitting control condition both conducted in a one-on-one experimenter-child setting. Executive functions were assessed with a behavioural and a computerized task directly following the intervention. Motor coordination experiences, self-control, and sociodemographics of the children were assessed with parental questionnaires.

Results: Performance in both executive function tasks did not differ between children in the physical activity condition compared to the control condition. However, individual differences in children's motor coordination experiences moderated the effectiveness of physical activity: Low levels of motor coordination experiences were linked to negative effects of physical activity on executive functions compared to a sitting activity, whereas a trend indicated positive effects from physical activity on executive functions with higher levels of motor coordination experiences.

Conclusion: Acute physical activity is a promising intervention for improving executive functions in young children when tailored to individual levels of motor coordination experiences. Early support to increase young children's motor coordination experiences may lead to executive function benefits of physical activity for more children.

Keywords: physical activity intervention, motor coordination experiences, young children, executive functions, self-regulation

Highlights

- Experimental study of acute physical activity (PA) effects on executive functions (EF)
- Acute PA does not consistently improve EF in young children.
- Acute PA has to be tailored to children's motor coordination level to improve EF.
- Increasing children's motor coordination experiences may foster PA benefits on EF.

Introduction

Self-regulation enables individuals to exert goal-directed actions and comprises the regulation of behavior, cognition, and emotion (Blair & Ursache, 2011). Self-regulation abilities are indispensable for social and academic functioning and play an important role already in early years of life. Executive functions represent the cognitive aspect of self-regulation. Evidence highlights the predictive power of early executive functions in preschool children for their successful transition from preschool or kindergarten to primary school, such as adaptive classroom behavior (Blair, 2002; Suchodoletz, Trommsdorff, Heikamp, Wieber, & Gollwitzer, 2009), and academic achievement over and above general intelligence and academic precursor skills (Blair & Razza, 2007; Preßler, Könen, Hasselhorn, & Krajewski, 2014). Executive functions can be separated into three components: (1) inhibition of prepotent responses, (2) working memory, and (3) shifting (Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000). The development of executive functions starts in early childhood and is characterized by important changes during the preschool years, leading for instance to an enhanced top-down control in inhibition tasks (Garon, Bryson, & Smith, 2008). Large improvements in executive functions are especially observable in the preschool age (i.e., 5 to 7 years; Röthlisberger, Neuenschwander, Cimeli, & Roebers, 2013). Concurrently, executive functions are pivotal for children in the age of 4 to 7 years since multiple adaption demands are imposed (e.g., transition from preschool/kindergarten to primary school; Petriwskyj, Thorpe, & Tayler, 2005). Thus, early interventions aiming to improve executive functions can lay the foundation for children's social functioning and learning as well as their academic success (Ursache, Blair, & Raver, 2012).

Physical Activity Interventions to Improve Executive Functions

A promising, yet understudied, approach for improving executive functions in children is the implementation of physical activity interventions[4] (Diamond & Lee, 2011) as these are low cost, easily accessible, and yield additional positive effects on children's mental and physical health (Ahn & Fedewa, 2011; Janssen & Leblanc, 2010). To date, the effects of physical activity to improve executive functions, over and above other cognitive processes (Colcombe & Kramer, 2003), have been predominantly demonstrated in adulthood (Barenberg, Berse, & Dutke, 2011) and especially in late adulthood (Colcombe & Kramer,

[4] Physical activity interventions are conceptualized in most of these studies as exercise referring to planned, structured and repetitive movements with the goal of increasing physical fitness or motor skills (Caspersen, Powell, & Christenson, 1985).

2003), while evidence in young children is still scarce as most reviews and meta-analyses are based on studies in children or adolescents aged 7 to 18 years (Best, 2010; Tomporowski, Lambourne, & Okumura, 2011; Verburgh, Konigs, Scherder, & Oosterlaan, 2014). Importantly, the development of executive functions undergoes fast changes during the preschool years (Romine & Reynolds, 2005), leading to the assumption that this age group could easily be targeted by interventions.

One meta-analysis focusing on cognitive functioning (e.g., as measured by academic readiness, intelligence quotient) demonstrated that younger children (i.e., 4 to 7 years) in particular benefitted from physical activity interventions by showing improved cognitive functioning with a moderately-strong effect (d = 0.40, SD = 0.26, n = 19 studies) compared to older children (i.e., 14-18 years, Sibley & Etnier, 2003). In the same way, a more recent meta-analysis focusing on executive functions indicates that physical activity interventions improve executive functions in 6- to 35-year-old participants with a strong effect (d = 0.52, 95%-CI = 0.29 - 0.76, n = 19 studies; Verburgh et al., 2014). Thus, initial evidence of positive physical activity effects on children's executive functions is available.

However, the meta-analyses reviewed and reported so far include studies implementing physical activity interventions varying greatly in their duration: improvements in executive functions have been demonstrated after chronic interventions, repeated regularly across a fixed time span (e.g., 1 hourly session per week for 6 months; Crova et al., 2014), and after acute interventions as single-bout sessions (e.g., one 20-min session; Best, 2012). Advantages of acute interventions are an easier implementation in experimental and applied settings and lower cost compared to chronic interventions. Research in adults has shown that acute physical activity interventions *lasting about 20 min* improve subsequent executive functions (Brisswalter, Collardeau, & Ren, 2002; Chang, Labban, Gapin, & Etnier, 2012), with particularly strong effects for *inhibition* of automatic or predominant responses (Barenberg et al., 2011). In the same way, some studies in children found acute physical activity to benefit solely inhibition with no effect on other executive function components (such as shifting and updating; Jäger, Schmidt, Conzelmann, & Roebers, 2014, Verburgh et al., 2014).

Reviewing the few available studies in children that have investigated the acute physical activity effects on executive functions reveals mixed findings (e.g., Verburgh et al., 2014). Some studies found improved inhibition performance (Best, 2012; Ellemberg & St-Louis-Deschênes, 2010; Jäger et al., 2014) with accompanying neurophysiological changes in the P3 amplitude indicating enhanced attention capacity during inhibition tasks (Hillman et

al., 2009; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). Other studies did not find acute activity effects on children's inhibition performance compared to sedentary control conditions (Mierau et al., 2014; Stein, 2016), but improvements in reaction times of working memory tasks (Cooper, Bandelow, Nute, Morris, & Nevill, 2012) and planning (Pirrie & Lodewyk, 2012). Consequently, reasons for these mixed results may ground in (a) the processes that lead physical activity to improve executive functions, (b) the characteristics of physical activity interventions and (c) the characteristics of the child as intervention recipient. Thus, these three aspects have to be taken into account when investigating whether physical activity can improve executive functions in young children and will be outlined in the following three sections.

Mechanisms of the Physical Activity Effects on Executive Functions

To explain the mechanisms underlying the benefits of physical activity on executive functions various processes have been discussed. These mechanisms can be divided into (1) physiological processes as well as (2) learning and developmental processes (Sibley & Etnier, 2003). First, physical activity induces physiological arousal leading to an increased cerebral blood flow in the prefrontal cortex, an increased release of brain neurotransmitters, like norepinephrine and dopamine, and of the brain-derived neurotrophic factor as shown in adults (Hötting & Röder, 2013; Winter et al., 2007). These physiological activity derivates may in turn facilitate allocation of brain resources necessary for executive function performance (e.g., Barenberg et al., 2011).

Second, developmental and embodied cognition theories propose that physical activity causes cognitive improvements in children by the bodily interactions and movements in space accompanying each physical activity (Piaget & Aebli, 1974; Wilson, 2002). In this way, neurophysiological measures provide evidence for a close interrelation between the cerebellum, activated during complex motor tasks, and the prefrontal cortex, activated during executive function tasks (Diamond, 2000; Serrien, Ivry, & Swinnen, 2007). Furthermore, motor and cognitive skills have been found to be closely associated during early childhood while this association seems to decline with age (Voelcker-Rehage, 2005) pointing to the importance of early physical activity experiences for cognitive improvements (Piaget & Aebli, 1974). Taken together, physical activity may improve executive functions via (1) physiological and (2) developmental processes. These pathways differ in their assumptions of which kind of physical activity may be most effective for improving executive functions.

Characteristics of Physical Activity Interventions

The physiological and developmental pathways lead to different conclusions about what characterizes an effective physical activity intervention. Characteristics of physical activity interventions can refer to (1) *quantitative* physiological demands and (2) *qualitative* cognitive or motor coordination demands. First, physiological arousal induced by physical activity depends on the intensity level of physical activity following an inverted U-relationship. Moderate-to-vigorous physical activity has been shown to be most effective for increasing the cerebral blood flow (Moraine et al., 1993) as well as for improving processing speed (McMorris & Hale, 2012) and is thus be assumed to be most effective for improving executive functions. Studies in children, however, comparing different intensity levels of acute physical activity interventions are missing so far. Nevertheless, some studies in children (7-11 years) indicate that acute physical activity interventions with moderate-to-vigorous intensity enhance executive functions, especially inhibition, more than sedentary control conditions (Ellemberg & St-Louis-Deschênes, 2010; Gawrilow, Stadler, Langguth, Naumann, & Boeck, 2016; Hillman et al., 2009).

Second, several studies highlight the importance of considering qualitative aspects of physical activity (Best, 2010; Pesce, 2012; Tomporowski, McCullick, Pendleton, & Pesce, 2015), as for instance the *cognitive engagement* during physical activity referring to the amount of cognitive resources, such as attention, needed to perform physical activities (Tomporowski et al., 2015). In physical activity interventions, cognitive engagement has been conceptualized by increased cognitive demands introduced as add-on to physical activity (e.g., via complex rules) or increased *motor coordination demands* inherent in physical activity (e.g., via coordination exercise; for a review: Best, 2010). Some studies show improvements in executive functions or attention after cognitively engaging physical activity over and above the effects of mere aerobic exercise, defined as physical activity without a cognitive add-on (Best, 2010; cognitively engaging games vs. aerobic exercise: Jäger et al., 2014, team games vs. aerobic exercise: Pesce, Crova, Cereatti, Casella, & Bellucci, 2009). Moreover, physical activity interventions with motor coordination demands, as for instance bilateral coordination tasks, have been shown to improve subsequent attention more than aerobic exercise in adolescents of an elite sports school (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008). In contrast, some other studies in children did not reveal advantages of physical activity interventions with additional cognitive or motor coordination demands compared to mere aerobic exercise regarding executive function

improvements (Best, 2012; Jäger, Schmidt, Conzelmann, & Roebers, 2015; Palmer, Miller, & Robinson, 2013; Stein, 2016).

In sum, the few available studies support the notion that an intervention with moderate-to-vigorous intensity and cognitive engagement, such as motor coordination demands, seems to be most effective for improving executive functions in young children as both pathways are addressed. However, due to the ambiguous results for interventions implementing cognitive engagement, characteristics of the child as intervention recipient may further moderate the effects on executive functions.

Characteristics of the Child as Intervention Recipient

When focusing on the acute effects of physical activity on executive functions the participant's previous experiences with physical activity may be an influential moderator (Pesce, 2009). However, individual differences resulting from chronic physical activity participation, such as the aerobic fitness level or motor coordination experiences, have been largely ignored in previous research.

Importantly, when focusing on children during their preschool years, physical activity behavior in everyday life is characterized by short, spontaneous bouts of physical activity with varying intensity (de Bock et al., 2010). Stable, repetitive and endurance-oriented activities related to the aerobic fitness level are rarely present in early years. Thus, the extent of motor coordination experiences seems a valid characteristic of young children's physical activity. Preliminary evidence for the moderating influence of motor coordination stems from two studies: First, an acute coordination exercise intervention benefitted attention processes over and above a mere aerobic exercise in adolescents of an elite sports school with presumably high motor coordination skills (Budde et al., 2008). Second, children with deficits in motor coordination or developmental coordination disorder (ICD-10: F82; World Health Organization, 1990) have been found to show improved attention after having participated in a 6-month physical activity intervention with low cognitive engagement, but not with high cognitive engagement (Pesce et al., 2013). In return, children with normally developed motor coordination skills benefitted more from the cognitively demanding physical activity intervention than from the mere activity intervention. This finding is attributed to the *optimal challenge point* where characteristics of the physical activity intervention (e.g., cognitive engagement) have to match optimally to characteristics of the child (i.e., motor coordination experiences) to result in cognitive improvements. Consequently, physical activity

interventions developed for young children should match to the children's level of motor coordination development.

The Present Study

Previous research highlights the effectiveness of acute physical activity as one easy applicable intervention that benefits executive functions. Physical activity interventions with moderate-to-vigorous intensity and cognitive engagement seem most promising to improve executive functions. Furthermore, individual characteristics of intervention recipients such as motor coordination experiences seem to moderate intervention effects. To date, however, evidence of standardized experiments investigating effects of acute physical activity interventions on executive functions in young children is very limited (for exceptions: Mierau et al., 2014; Palmer et al., 2013; Stein, 2016). For children in the age of 4 to 7 years, executive functions are pivotal since this period imposes multiple demands on executive functions (Petriwskyj et al., 2005) and at the same time important developments of executive functions take place (Romine & Reynolds, 2005). Therefore, the current study investigates whether an acute physical activity intervention with moderate-to-vigorous intensity and motor coordination demands, compared to a non-physical control condition (i.e., sitting activity) enhances executive functions in young children aged 4 to 7 years. We expect that children show improved executive functions immediately after having participated in the physical activity intervention condition as compared to the control condition. Moreover, we want to explore the role of previous motor coordination experiences for the effectiveness of the intervention condition compared to the control condition in improving executive functions.

Methods

Sample and Design

In total, N = 103 children (46% female; age: M = 68.50 months, SD = 12.93) were enrolled in the study and randomly assigned to either an intervention or control condition. We used stratified randomization with four strata (i.e., girls/boys x young[4.0-5.9years]/old[6.0-7.9years]) starting with a block length of 6 followed by blocks of 4 to account for influences of age (Romine & Reynolds, 2005) and gender (Matthews, Ponitz, & Morrison, 2009). An a priori power analysis indicated that 50 participants in each condition are needed to have 80% power for detecting a medium sized effect (e.g., Sibley & Etnier, 2003) with the .05 probability for alpha error. Recruitment took place via flyers distributed in preschools, kindergartens and primary schools as well as send out via E-mail to students and staff of a

German university. Parents gave written informed consent before study participation and children received a €7 voucher for local bookstore for their participation. The study was approved by the local ethics review board.

Measures

Executive functions.

Head-Toes-Knees-Shoulders task. To assess executive function performance we used a standardized behavioral test, called the *Head-Toes-Knees-Shoulders task* ([HTKS], Ponitz, McClelland, Matthews, & Morrison, 2009; McClelland & Cameron, 2012). According to the authors, the HTKS measures attention processes, working memory and inhibition manifested in gross-motor actions (Ponitz et al., 2009, p. 605). Children are instructed to perform the opposite movement of what the experimenters tells them to do, as for instance to touch their head when asked to touch their feet. The task is divided into three blocks with increasing difficulty each starting with a short introduction and practice trials with feedback before the administration of 10 test trials. Children have to achieve at least 4 points for getting into a subsequent block and testing is stopped once they achieve less than 4 points in one block. The first block starts with one pair (i.e., *head-toes*), the second block additionally introduces another pair (i.e., *shoulders-knees*), and in the third block rules are switched (i.e., new pairs: *head-knees*, *shoulders-feet*). Children are videotaped during the task and blind raters code the responses as being correct (2), incorrect (0) or a corrected response (1) where the child is starting with an incorrect movement but then correcting it to a correct response. Response accuracy (i.e., sum scores across all blocks, ranging from 0 to 60) coded by the blind raters serves as indicator of executive function performance. Inter-rater reliability was calculated by having three blind raters to code participants with partly overlap between rating subjects (Krippendorff's α = .96; n = 50; Krippendorff, 2004). The high inter-rater reliability is in line with previous findings (Cohen's κ = 0.90; Ponitz et al., 2009). For the analyses, mean ratings of the blind raters are used, but for 4 children in-situ experimenter ratings were used as no videotape was available due to technical issues.

Day-Night Stroop like task. To measure executive functions we also used the computer-based child-adapted *Day-Night Stroop like task* ([DNS], original: Gerstadt, Hong, & Diamond, 1994; modification: Berlin & Bohlin, 2002). In contrast to the original stroop task (Stroop, 1935) pictures are used as stimuli instead of words. Children are instructed to name the opposite of what they actually see (e.g., say "girl" for a picture of a "boy") after having learned about four picture pairs (i.e., day-night, small-big, girl-boy, up-down) shown as

laminated paper cards in eight practice trials. To ensure timely precise presentation, stimuli are from then on presented on a laptop using the Software DirectRT (Jarvis, 2008). Experimenters instruct the children to answer as fast and correct as possible when seeing a stimulus. Children start with a second practice trial block on the laptop followed by two testing blocks with 24 trials each. Each trial starts with a black screen and a centered white fixation cross (1500ms) followed by stimulus presentation (first block: 1500ms, second block: 1000ms) and finally a black screen (1000ms). Thus, the inter-stimulus interval is at least 1500ms and the response time can take up to 2500ms (first block). Responses are categorized as being correct (2) or incorrect (0) or corrected errors (1) where the child starts with saying the incorrect response but then gives the correct response. Response accuracy serves as indicator of inhibition capacity and thus, sum scores across both blocks (i.e., ranging from 24 to 96) are used for the analyses.

Manipulation check.

Heart rate. Interventions were developed to impose a moderate intensity level (i.e., physical activities) on children in contrast to control sessions demanding low intensity (i.e., sitting activity). Using an electrocardiographic device (ekgMove; Movisens®, Karlsruhe, Germany) heart rate was measured objectively to measure physical activity intensity levels. The small device (62.3mm x 38.6mm x 10.5mm) was placed at children's thorax, at the right of the sternum, with adhesive disposable electrodes and band aid. Raw data were aggregated into 15s-epochs to include also short activity bouts (e.g., Bayer, Jarczok, Fischer, Kries, & Bock, 2012) and the average heart rates per epoch were extracted using DataAnalyzer 1.7 (Movisens®, Karlsruhe, Germany). Raw data was then screened for artefacts defined either as (a) heart rates below 60 beats per minute (bpm; e.g., Fleming et al., 2011) or above 250 bpm (e.g., de Bock et al., 2010) or (b) multiple consecutive records with the very same heart rate. In both cases single records were deleted. If multiple records (i.e., > 30%) of one child were missing, the whole recording was excluded from the analyses. Consequently, valid data consisted of mean heart rates for every 15-s epoch ranging from 60 to 250 bpm.

Affect and enjoyment. Children's current affect was assessed using the self-assessment manikin scale (original: Bradley & Lang, 1994, German version: Conzelmann, McGregor, & Pauli, 2015). We selected age-appropriate affect adjectives based on previous adaptions for the use in children (Sharp, van Goozen, & Goodyer, 2006) and further reduced the number of affect adjectives to two for each affect item. Consequently, affect was measured on a 5-point bipolar scale with two items representing the dimensions of (a) valence

(*unhappy, bad-tempered* to *happy, good-tempered*) and (b) arousal (*calm, relaxed* to *exited, awakened*). After the experimenter had described the poles of the scale, children were instructed to indicate their current affect by pointing on one of the 5 manikins showing varying expressions that fitted best to their affect (see material in Appendix A). Children's enjoyment of the intervention or control condition was assessed with four items that referred to enjoyment and fun during the task, perceived difficulty, perceived exhaustion and motivation to repeat the task (based on Freitas & Higgins, 2002). Answers were given on a 3-point ordinal scale with child-oriented graphics of an empty, half-full and full barrel of water (Bergström et al., 2015). Children pointed to the barrel labeled by the experimenter with potential answers, as for instance with "no fun at all", "medium fun", or "a lot of fun".

Moderator variable.

Motor coordination experiences. Children's motor coordination experiences were assessed using a short parent questionnaire for preschool children (Bayer et al., 2012). Importantly, the items refer to various physical activities differing in their motor and coordination demands (see Appendix A). Across seven items parents rated how often their child regularly engages in the indicated activity (e.g., "How often does your child play with a ball?") on a 5-point ordinal scale ranging from 1 (e.g., *never*) to 5 (e.g., *every day*). Parent ratings for each item are classified as indicator of high (i.e., value of +1) or low habitual experience of the mentioned activity (i.e., value of -1) depending on the frequency rated for the item (Bayer et al., 2012). Sum scores[5] of all item responses were calculated for each child. As low frequent activities have negative values, these are subtracted from the amount of highly frequent activities. Sum scores range from -7 to +7. These questionnaire scores have been shown to be positively associated with objectively recorded physical activity in preschool children's daily lives (Bayer et al., 2012) as well as with preschool children's performance in a motor test (Bayer, Bolte, Morlock, Ruckinger, & Kries, 2009).

[5] Bayer and colleagues (2012) categorized the sum score into three equidistant categories of low, moderate and high levels of physical activity. However, we used the sum score to avoid reducing the available information by further categorization and since the sum score followed a normal distribution in our sample. Moreover, we ran all analyses with the categorized score and this did not change the results.

Background variables.

Self-control. Parents rated their children's dispositional capacity of self-control via the brief *self-control scale* (Tangney, Baumeister, & Boone, 2004) translated to German (Bertrams & Dickhäuser, 2009) and adapted for parental ratings (Rauch, Gawrilow, Schermelleh-Engel, & Schmitt, 2014). Across 13 items targeting thought control, emotion regulation, impulse control, action persistence, action monitoring, and the overcoming of negative habits (e.g., *My child is good at resisting temptation.*), parents indicate to which extent the statements matched their child's behavior in general on a 5-point Likert scale ranging from 1 (*not at all*) to 5 (*exactly*), with higher sum scores representing lower self-control (i.e., range from 13 to 65). Scores on the self-control scale are positively associated with behavior problems (e.g., subscale of the Strength and Difficulties Questionnaire) and negatively associated with academic performance (Rauch et al., 2014). In the present study, the questionnaire shows adequate reliability (i.e., Guttman's $\lambda_2 = .85$) in line with previous results (Rauch et al., 2014).

Demographic data. Finally, parents indicated demographics of their child (e.g., sex, age, height, weight, German citizenship, language spoken at home) and of the family (e.g., highest school degree of both parents).

Procedure

The study took place in a one-on-one experimenter-child setting in a quiet room either in the university or in the kindergarten. If the child felt uncomfortable parents were allowed to sit in the back of the room (this was true for 10 children). Experimenters were six research assistants trained to follow standardized instructions in repeated training sessions, including for instance an online training for administering the HTKS. The session consisted of two parts with Part 1 including the experimental manipulation (i.e., intervention or control condition) and with Part 2 including the assessment of dependent variables (e.g., executive function tasks). Both parts were conducted by different experimenters, so the experimenter of Part 2 was blind to the condition in which the child had participated previously to avoid any prompting in line with the hypothesized outcome (e.g., Rosenthal effect; Rosenthal & Jacobson, 1966). Both experimenters welcomed the child at the beginning of each session, afterwards Experimenter 2 left. Experimenter 1 introduced shortly the study goals and ensured that the child was able to move without any pain. Then, the experimenter asked the child about its current *affect* and attached the electrocardiographic device for assessing the *heart*

rate to its thorax. Subsequently, the intervention or control condition started whereby the child was videotaped.

Intervention condition. In the intervention condition, children performed four different activity games embedded in a child-oriented story about a rabbit and a hedgehog. Each game was especially developed to impose a moderate-to-vigorous intensity level (approximately 55-90% of the maximal heart rate[6]; Norton, Norton, & Sadgrove, 2010) and to demand motor coordination skills. To ensure these demands, games were adaptive so that children received more difficult tasks with increasing performance (i.e., two difficulty levels in each game). Each game started with a short introduction and the child had 3 minutes for performing the instructed activities. To maintain motivation, the child received a stamp for each round performed within a game.

Control condition. In the control condition, the experimenter read a story about rabbit and hedgehog to the child and asked easy and open questions at regular intervals. The child received a stamp for each answer or comment to the questions. Both conditions were designed to last 18 minutes.

After the intervention or control condition Experimenter 1 left the room and Experimenter 2 returned. The child indicated its current *affect* and was asked about its *enjoyment* of the tasks with rabbit and hedgehog (i.e., referring to the intervention/control condition). Then, the *HTKS* and subsequently the *DNS* were performed. Afterwards, the child indicated its enjoyment of the HTKS and DNS. Finally, the experimenter thanked the child for its participation and rewarded it with a voucher. During the session the experimenters noted the exact time of beginning and ending of the intervention and control condition. The whole session was designed to last 50 minutes.

Statistical Analyses

To analyze any pre-existing differences between children assigned to conditions two-sided t-tests were used in case of continuous and normally distributed variables. In case of non-normally distributed variables we used Mann-Whitney-U tests and for nominal variables Chi^2 tests. To test intervention effects in executive functions we ran regression analyses for each measure of executive functions as outcome variable (i.e., HTKS, DNS) with condition as predictor. Additionally, we included motor coordination experiences as predictor and moderator in the regression analyses and also controlled for covariates, such as age, gender

[6] In the present study we refer to the maximal heart rate by relying on age-dependent norm values (e.g., Mahon, Marjerrison, Lee, Woodruff, & Hanna, 2010; van der Cammen-van Zijp et al., 2010).

and self-control. All predictors were centered at the grand mean or dummy-coded. Simple slope analyses (Aiken & West, 1991; Dawson, 2014) and the Johnson-Neyman Technique (Johnson & Fay, 1950) were used to probe significant interactions and to identify the range of significant values of the moderator. The level of significance was set to $p < .05$ for all analyses.

Results

Preliminary Analyses and Manipulation Check

From the total sample of 103 children, 51 children were randomly assigned to the intervention condition and 52 children in the control condition. Children in both conditions did not differ with respect to background variables, such as age, gender, body mass index, mother tongue, parent's graduation level, self-control or motor coordination experiences. Besides, the conditions did not differ in testing characteristic, as for instance in the setting of the condition (i.e., university vs. kindergarten) or timing of the session (i.e., morning vs. afternoon).

To ensure successful manipulation, heart rates during the conditions were compared with 71 children providing valid data (intervention: $n = 37$; control: $n = 34$). As expected, mean heart rates during the intervention condition were significantly higher than during the control condition ($d = 2.30$) indicating an increased physiological arousal in the intervention condition. The mean heart rate in the intervention condition ($M = 127.30$ bpm, $SD = 10.61$) corresponded to 65% of the maximal heart rate found in previous studies (e.g., van der Cammen-van Zijp et al., 2010) with individual heart rates ranging from 54% to 79% of the estimated maximal heart rate. In addition, children did not differ in their enjoyment of the conditions. However, children in the intervention condition perceived this condition as more difficult and more exhausting than children in the control condition and were also less willing to repeat the condition. Children's change in affect ratings (i.e., valence, arousal) from pre- to post-condition did not differ between the intervention and control condition. Details of these preliminary analyses and manipulation check are given in Table 1.

Intervention Effects on Executive Functions

Head-Toes-Knees-Shoulders task. From 103 children, 3 children refused to take part in the HTKS and one parent did not indicate his/her child's self-control, that served as a covariate, thus 4 cases were excluded from the regression analyses. These children did neither differ with respect to their assignment into the intervention or control condition nor with

respect to relevant background variables, such as motor coordination experiences or self-control. For performance in the HTKS, regression analyses revealed no main effect of condition in contrast to our hypothesis (see Table 2). Thus, children having participated in the intervention condition did not show improved performance compared to children in the control condition. However, there was a significant interaction effect between condition and motor coordination experiences (see Figure 1). The interaction was probed by testing the conditional effects of the intervention and control condition at three levels of motor coordination experiences, one standard deviation below the mean, at the mean, and one standard deviation above the mean. As shown in Table 3, the condition was significantly related to HTKS performance when the level of motor coordination experiences was one standard deviation below the mean (p = .015), but not when the level of motor coordination experiences was at the mean or one standard deviation above the mean (p >.05). The coefficients of the simple slopes reflect an increasing trend, thus the higher the level of motor coordination experiences the better the children performed in the HTKS after the physical activity condition compared to the control condition. In addition, the Johnson-Neyman technique showed that the relationship between condition and HTKS performance was significant when the level of motor coordination experiences was 0.51 standard deviations below the mean but not significant with moderate or high levels of the level of motor coordination experiences. Children with lower levels of motor coordination experiences (i.e., ≤ -0.51 SD below the sample mean) performed worse after the physical activity condition compared to the control condition.

The interaction effect (β = 0.31) was the second most influential predictor (after age, β = 0.60) of performance in the HTKS. The inclusion of the interaction term resulted in an additional 4% of explained variance in the HTKS compared to the explained variance of the model without the interaction term. In line with previous findings (e.g., age: Romine & Reynolds, 2005; gender: Matthews et al., 2009), there were significant main effects of age and gender indicating improved performance for older children (β = 0.60) and for girls compared to boys (β = 0.16). Motor coordination experiences and self-control did not predict children's HTKS performance.

Day-Night-Stroop like task. From 103 children, one case was excluded from the regression analyses due to the missing value of the child's self-control. For performance in the DNS, regression analyses revealed no main effect of condition. Motor coordination experiences as well as the interaction between condition and motor coordination experiences

did not significantly predict performance. There was a main effect of age indicating that children showed improved performance with increasing age ($\beta = 0.37$). Gender and self-control did not predict children's performance.

Discussion

This experimental study investigated whether executive functions in young children aged 4 to 7 years can be improved by a an acute moderate-to-vigorous physical activity intervention with motor coordination demands compared to a non-physical control condition. In contrast to our hypothesis, children being randomly assigned and having participated in the physical activity intervention did not differ significantly in their executive function performance from children having participated in the control condition. However, further analyses revealed individual differences in motor coordination experiences as a moderator for the effectiveness of physical activity compared to the control condition in one of two executive function measures, as it was hypothesized from previous results (Pesce et al., 2013). Children with low levels of motor coordination experiences performed worse after the physical activity intervention compared to the control condition with regard to inhibition performance in a behavioral task, but not in a computerized executive function task. Moreover, descriptively, there was a trend indicating that children with higher levels of motor coordination experiences benefit more from physical activity than from a sitting activity.

Intervention Effects on Executive Functions

The finding that acute physical activity did not improve the inhibition component of executive functions more than a sitting activity stands in contrast to other studies in children (Best, 2012; Ellemberg & St-Louis-Deschênes, 2010; Hillman et al., 2009; Jäger et al., 2014; Pontifex et al., 2013), but is in line with some studies in children (Cooper et al., 2012; Jäger et al., 2015; Mierau et al., 2014; Palmer et al., 2013; Pirrie & Lodewyk, 2012; Stein, 2016). Importantly, the null finding with respect to the physical activity intervention cannot be attributed to existing differences in children's age, gender, body mass index, parent-reported motor coordination experiences or parent-reported self-control, nor to differential effects in children's enjoyment or changes in affect from pre- to post-condition between the conditions. In addition, ceiling or floor effects in the executive function tasks were not present as evidenced by accuracy scores in line with previous findings (HTKS: McClelland et al., 2014; DNS: Thorell, 2007). Further explanations for the missing positive effect of physical activity on executive functions could be due to (a) differential effects in young children, or (b) the

content of our physical activity intervention. First, there is limited evidence available in young children demonstrating that acute physical activity improves subsequent executive functions (e.g., Jäger et al., 2014). Thus, it could be that the positive activity effects shown in adults and older children do not generalize to children aged 4 to 7 years. Moreover, young children differ considerably with regard to their current developmental state of cognitive and motor skills. These individual differences in executive functions as well as motor coordination skills may moderate the activity effects on executive functions. The null finding in the present study may thus be attributable to mixed effects depending on children's individual characteristics. In line with previous findings (Pesce et al., 2013), we included children's motor coordination experiences as moderator of the activity effects on executive functions revealing further results (see next section of Discussion).

Second, the physical activity intervention used in the present study could be characterized with regard to its (a) qualitative motor coordination demands and (b) quantitative intensity demands. Physical activity interventions with motor coordination demands have been previously shown to benefit executive functions in adolescents (Budde et al., 2008). Importantly, physical activity with motor coordination demands in particular should lead to improved executive functions by addressing the pathway of developmental processes. It could be argued, however, that our intervention may have not been optimal for addressing developmental processes due to its level of motor coordination demands. It is possible that the level of motor coordination demands implemented in the physical activity interventions has differential effects depending on a child's previous physical activity experiences and developmental level (Pesce et al., 2013). Thus, future studies manipulating the amount of children's previous experiences, as for instance longitudinal intervention studies, are needed.

As outlined above, the intensity of physical activity may be one critical factor influencing the effectiveness of physical activity interventions. In the present study, mean heart rate during the physical activity intervention indicated a moderate-to-vigorous intensity (i.e., 65% of estimated maximal heart rate) that has been previously shown to benefit executive functions (e.g., Hillman et al., 2009). However, when looking on the time course of children's heart rates it becomes obvious that within each child heart rates fluctuated considerably from moment-to-moment as it is also usually observable in young children's physical activity in daily life (de Bock et al., 2010). Thus, the physical activity intervention used in the present study, consisting of four child-adapted activity games, has the advantage to provide higher ecological validity, but differs from previous physical activity interventions

conducted with older children or in the lab where participants are instructed to perform steady and endurance-oriented activities on a treadmill or ergometer (e.g., Hillman et al., 2009). Future research should address whether there are differences in the effectiveness of physical activity interventions with fluctuating versus steady physiological demands.

Moderating Effect of Motor Coordination Experiences

Individual differences in motor coordination experiences moderated the effectiveness of the physical activity intervention to improve executive functions. Children with low levels of motor coordination experiences performed worse after the physical activity intervention compared to the non-physical control condition in a behavioral executive function task. This result may be explained by neurophysiological evidence and the theoretical notion of an optimal challenge point (Pesce et al., 2013). Based on the finding of a close interrelation between the cerebellum, activated during motor coordination tasks, and the prefrontal cortex, activated during executive function tasks (Diamond, 2000; Serrien et al., 2007), it might be that the cerebellum is only activated during coordination exercise if a certain amount of motor coordination experience is available and that instead children with low levels of motor coordination experiences show different neurophysiological activation patterns. Support for this hypothesis stems from studies in children with developmental coordination disorder demonstrating that they show under-activation in cerebellar networks compared to normally developed peers (Zwicker, Missiuna, Harris, & Boyd, 2011). In the theoretical term of an optimal challenge point (Pesce et al., 2013) children with low levels of motor coordination experiences may have been overtaxed by the physical activity intervention with motor coordination demands.

Moreover, we found that the higher the level of motor coordination experiences the better the children's inhibition performance after the physical activity intervention compared to the control condition. So, in line with the notion of an optimal challenge point, it could be that high levels of motor coordination experiences are a prerequisite to benefit from a physical activity intervention with motor coordination demands. Likewise one study showing positive effects of an intervention with motor coordination demands was conducted in elite sports students that presumably have sampled a wide range of motor coordination experiences (Budde et al., 2008).

Importantly, the moderating effect of motor coordination experiences was found for inhibition performance assessed in a behavioral task (i.e., Head-Toes-Knees-Shoulder task), but not in a computerized task (i.e., Day-Night-Stroop like task). These tasks differ in the way

how answers are given and thus require either motor or verbal inhibition (Campbell, Eaton, & McKeen, 2002). Consequently, the moderating effect of children's motor coordination experiences is limited to a *near-transfer* outcome measure requiring motor responses that is strongly linked to the intervention content. The computerized task requires verbal answers and can be interpreted as a far-transfer measure that is not affected by individual differences in motor coordination experiences in the present study. To explain this specific effect for children with different levels of motor coordination experiences in the near-transfer outcome, physical activity may have influenced executive functions via the learning and developmental pathway. In line with embodiment theories it could be that movement-induced activation of cognitive networks prime subsequent motor performance in the executive function task (e.g., Wilson, 2002). Further studies are needed to corroborate this assumption.

Limitations

The present study has several limitations. First, the present finding of individual differences in motor coordination experiences moderating the effectiveness of physical activity to improve executive functions needs to be corroborated in future studies with larger samples. These results will allow to draw conclusions about general cut-offs of motor coordination experiences needed for physical activity benefits on executive functions. Second, in the present study we assumed that physical activity with additional motor coordination demands might be more beneficial to improve executive functions than a mere physical activity intervention as both pathways – (1) physiological as well as (2) learning and developmental pathway – are addressed. However, to further test this assumption studies are needed that (a) directly test the assumed mechanisms and that (b) compare physical activity interventions with varying intensities and varying motor coordination demands. Future research should also address assessment strategies of the absolute level of motor coordination demands to improve comparability across physical activity interventions. Third, we focused on the effects of acute physical activity on subsequent executive functions. Questions about the temporal sustainability of the effects remain unanswered and require additional assessments. Fourth, we relied on a parent questionnaire for assessing children's motor coordination experiences. Future studies may corroborate our findings by assessing motor coordination more objectively using standardized tests (e.g., {Petermann 2008 #523}). Fifth, we tried to develop the physical activity intervention and control condition as similar as possible and also included a comprehensive manipulation check (e.g., heart rate measures, enjoyment of intervention). However, the duration varied between both conditions in the way

of a slightly (on average 4.30 min) longer physical activity intervention than the control condition. Although there were no differences between the conditions with regard to children's enjoyment, future studies should enforce more parallel durations to enable more standardized intervention comparisons.

Conclusions

To our knowledge, this is the first experimental study in young children aged 4 to 7 years investigating the effectiveness of physical activity for executive functions and the moderating role of individual differences in motor coordination experiences. In light of the pivotal role of early executive functions for future success in social and academic life, our finding that physical activity with cognitive engagement can potentially influence subsequent executive function performance in children with high levels of motor coordination experiences is encouraging. Consequently, physical activity interventions should be designed to match the individual level of motor coordination experience to constitute an optimal challenge point. Moreover, physical activity interventions that aim at increasing children's motor coordination experiences can further extend the benefits on executive functions for children with low levels of motor coordination experiences. Early educational institutions can support young children by offering physical activity with a wide diversity of motor coordination demands as it has been previously proposed (Roth et al., 2010). For introducing evidence-based physical activity interventions in a large scale in kindergartens and schools, future standardized studies in samples of young children are indispensable.

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

Aiken, L. S., & West, S. G. (1991). *Testing and interpreting interactions in multiple regression*: Sage Publications.

Barenberg, J., Berse, T., & Dutke, S. (2011). Executive functions in learning processes: Do they benefit from physical activity? *Educational Research Review, 6*(3), 208–222. doi:10.1016/j.edurev.2011.04.002

Bayer, O., Bolte, G., Morlock, G., Ruckinger, S., & Kries, R. von. (2009). A simple assessment of physical activity is associated with obesity and motor fitness in pre-school children. *Public health nutrition, 12*(8), 1242–1247. doi:10.1017/S1368980008003753

Bayer, O., Jarczok, M., Fischer, J., Kries, R. von, & Bock, F. de. (2012). Validation and extension of a simple questionnaire to assess physical activity in pre-school children. *Public health nutrition, 15*(9), 1611–1619. doi:10.1017/S1368980012001243

Bergström, K.; Spilski, J.; Mayerl, J.; Möhler, U.; Lachmann, T. & Klatte, M. (2015). Effects of aircraft noise on annoyance and quality of life in German children near Frankfurt/Main airport: Results of the NORAH (noise-related annoyance, cognition, and health)-study. *Proceedings of Euronoise 2015,* Maastricht.

Berlin, L., & Bohlin, G. (2002). Response inhibition, hyperactivity, and conduct problems among preschool children. *Journal of Clinical Child and Adolescent Psychology, 31*(2), 242–251.

Bertrams, A., & Dickhäuser, O. (2009). Messung dispositioneller Selbstkontroll-Kapazität: Eine deutsche Adaptation der Kurzform der Self-Control Scale (SCS-K-D) [Measuring dispositional self-control capacity. A German adaptation of the short form of the Self-Control Scale (SCS-K-D)]. *Diagnostica, 55*(1), 2–10. doi:10.1026/0012-1924.55.1.2

Best, J. R. (2010). Effects of physical activity on children’s executive function: Contributions of experimental research on aerobic exercise. *Developmental Review, 30*(4), 331–351. doi:10.1016/j.dr.2010.08.001

Best, J. R. (2012). Exergaming immediately enhances children's executive function. *Developmental psychology, 48*(5), 1501–1510. doi:10.1037/a0026648

Blair, C. (2002). School readiness: Integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. *American Psychologist, 57*(2), 111–127. doi:10.1037//0003-066X.57.2.111

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child development, 78*(2), 647–663. doi:10.1111/j.1467-8624.2007.01019.x

Blair, C., & Ursache, A. (2011). A bidirectional model of executive functions and self-regulation. In R. F. Baumeister & K. D. Vohs (Eds.), *Handbook of self-regulation* (2nd ed., pp. 300–320). New York, NY: Guilford Press.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49–59. doi:10.1016/0005-7916(94)90063-9

Brisswalter, J., Collardeau, M., & Ren, A. (2002). Effects of acute physical exercise characteristics on cognitive performance. *Sports Medicine, 32*(9), 555–566. doi:10.2165/00007256-200232090-00002

Budde, H., Voelcker-Rehage, C., Pietraßyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441*(2), 219–223. doi:10.1016/j.neulet.2008.06.024

Campbell, D. W., Eaton, W. O., & McKeen, N. A. (2002). Motor activity level and behavioural control in young children. *International Journal of Behavioral Development, 26*(4), 289–296. doi:10.1080/01650250143000166

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise and physical fitness: definitions and distinctions for health-related research. *Public Health Rep, 100,* 126–131.

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: a meta-analysis. *Brain Research, 1453,* 87–101. doi:10.1016/j.brainres.2012.02.068

Colcombe, S., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychological Science, 14*(2), 125–130.

Conzelmann, A., McGregor, V., & Pauli, P. (2015). Emotion regulation of the affect-modulated startle reflex during different picture categories. *Psychophysiology, 52*(9), 1257–1262. doi:10.1111/psyp.12450

Cooper, S. B., Bandelow, S., Nute, M. L., Morris, J. G., & Nevill, M. E. (2012). The effects of a mid-morning bout of exercise on adolescents' cognitive function. *Mental Health and Physical Activity, 5*(2), 183–190. doi:10.1016/j.mhpa.2012.10.002

Crova, C., Struzzolino, I., Marchetti, R., Masci, I., Vannozzi, G., Forte, R., & Pesce, C. (2014). Cognitively challenging physical activity benefits executive function in overweight children. *Journal of sports sciences, 32*(3), 201–211. doi:10.1080/02640414.2013.828849

Dawson, J. F. (2014). Moderation in Management Research: What, Why, When, and How. *Journal of Business and Psychology, 29*(1), 1–19. doi:10.1007/s10869-013-9308-7

de Bock, F., Menze, J., Becker, S., Litaker, D., Fischer, J., & Seidel, I. (2010). Combining accelerometry and HR for assessing preschoolers' physical activity. *Medicine and science in sports and exercise, 42*(12), 2237–2243. doi:10.1249/MSS.0b013e3181e27b5d

Diamond, A. (2000). Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child development, 71*(1), 44–56.

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science, 333*(6045), 959–964. doi:10.1126/science.1204529

Ellemberg, D., & St-Louis-Deschênes, M. (2010). The effect of acute physical exercise on cognitive function during development. *Psychology of Sport and Exercise, 11*(2), 122–126. doi:10.1016/j.psychsport.2009.09.006

Fleming, S., Thompson, M., Stevens, R., Heneghan, C., Plüddemann, A., Maconochie, I., . . . Mant, D. (2011). Normal ranges of heart rate and respiratory rate in children from birth to 18 years of age: A systematic review of observational studies. *The Lancet, 377*(9770), 1011–1018. doi:10.1016/S0140-6736(10)62226-X

Freitas, A. L., & Higgins, E. T. (2002). Enjoying Goal-Directed Action: The Role of Regulatory Fit. *Psychological Science, 13*(1), 2–6.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: a review using an integrative framework. *Psychological Bulletin, 134*(1), 31–60. doi:10.1037/0033-2909.134.1.31

Gawrilow, C., Stadler, G., Langguth, N., Naumann, A., & Boeck, A. (2016). Physical activity, affect, and cognition in children with symptoms of ADHD. *Journal of Attention Disorders, 20*(2), 151–162. doi:10.1177/1087054713493318

Gerstadt, C. L., Hong, J. H., & Diamond, A. (1994). The relationship between cognition and action: performance of children 3 1/2-7 years old on a Stroop-like day-night test. *Cognition, 53,* 129–153.

Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience, 159*(3), 1044–1054. doi:10.1016/j.neuroscience.2009.01.057

Hötting, K., & Röder, B. (2013). Beneficial effects of physical exercise on neuroplasticity and cognition. *Neuroscience and biobehavioral reviews, 37*(9 Pt B), 2243–2257. doi:10.1016/j.neubiorev.2013.04.005

Jäger, K., Schmidt, M., Conzelmann, A., & Roebers, C. M. (2014). Cognitive and physiological effects of an acute physical activity intervention in elementary school children. *Frontiers in Psychology, 5,* 1473. doi:10.3389/fpsyg.2014.01473

Jäger, K., Schmidt, M., Conzelmann, A., & Roebers, C. M. (2015). The effects of qualitatively different acute physical activity interventions in real-world settings on executive functions in preadolescent children. *Mental Health and Physical Activity, 9,* 1–9. doi:10.1016/j.mhpa.2015.05.002

Janssen, I., & Leblanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 7,* 40. doi:10.1186/1479-5868-7-40

Jarvis, B. G. (2008). DirectRT (Version 2008.1.0.13) [Computer Software]. New York, NY: Empirisoft Corporation.

Johnson, P. O., & Fay, L. C. (1950). The Johnson-Neyman technique, its theory and application. *Psychometrika, 15*(4), 349–367.

Léger, L. A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences, 6*(2), 93–101. doi:10.1080/02640418808729800

Lehto, J. E., Juujarvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology, 21,* 59–80.

Mahon, A. D., Marjerrison, A. D., Lee, J. D., Woodruff, M. E., & Hanna, L. E. (2010). Evaluating the prediction of maximal heart rate in children and adolescents. *Research Quarterly for Exercise & Sport, 81*(4), 466–471. doi:10.1080/02701367.2010.10599707

Matthews, J. S., Ponitz, C. C., & Morrison, F. J. (2009). Early gender differences in self-regulation and academic achievement. *Journal of Educational Psychology, 101*(3), 689–704. doi:10.1037/a0014240

McClelland, M. M., & Cameron, C. E. (2012). Self-regulation in early childhood: Improving conceptual clarity and developing ecologically valid measures. *Child Development Perspectives, 6*(2), 136–142. doi:10.1111/j.1750-8606.2011.00191.x

McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014). Predictors of early growth in academic achievement: the head-toes-knees-shoulders task. *Frontiers in Psychology, 5,* 599. doi:10.3389/fpsyg.2014.00599

McMorris, T., & Hale, B. J. (2012). Differential effects of differing intensities of acute exercise on speed and accuracy of cognition: a meta-analytical investigation. *Brain and cognition, 80*(3), 338–351. doi:10.1016/j.bandc.2012.09.001

Mierau, A., Hulsdunker, T., Mierau, J., Hense, A., Hense, J., & Struder, H. K. (2014). Acute exercise induces cortical inhibition and reduces arousal in response to visual stimulation in young children. *International journal of developmental neuroscience : the official journal of the International Society for Developmental Neuroscience, 34,* 1–8. doi:10.1016/j.ijdevneu.2013.12.009

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive psychology, 41*(1), 49–100. doi:10.1006/cogp.1999.0734

Moraine, J. J., Lamotte, M., Berre, J., Niset, G., Leduc, A., & Naeije, R. (1993). Relationship of middle cerebral artery blood flow velocity to intensity during dynamic exercise in normal subjects. *European journal of applied physiology and occupational physiology, 67*(1), 35–38.

Norton, K., Norton, L., & Sadgrove, D. (2010). Position statement on physical activity and exercise intensity terminology. *Journal of Science and Medicine in Sport, 13*(5), 496–502. doi:10.1016/j.jsams.2009.09.008

Palmer, K. K., Miller, M., & Robinson, L. E. (2013). Acute Exercise Enhances Preschoolers' Ability to Sustain Attention. *Journal of Sport & Exercise Psychology, 35,* 433–437.

Pesce, C. (2009). An integrated approach to the effect of acute and chronic exercise on cognition: the linkd role of individual and atsk constraints. In T. McMorris, P. D.

Tomporowski, & M. Audiffren (Eds.), *Exercise and cognitive function* (pp. 213–225). Chichester, UK, Hoboken, NJ: Wiley-Heinrich.

Pesce, C. (2012). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of sport & exercise psychology, 34*(6), 766–786.

Pesce, C., Crova, C., Cereatti, L., Casella, R., & Bellucci, M. (2009). Physical activity and mental performance in preadolescents: Effects of acute exercise on free-recall memory. *Mental Health and Physical Activity, 2*(1), 16–22. doi:10.1016/j.mhpa.2009.02.001

Pesce, C., Crova, C., Marchetti, R., Struzzolino, I., Masci, I., Vannozzi, G., & Forte, R. (2013). Searching for cognitively optimal challenge point in physical activity for children with typical and atypical motor development. *Mental Health and Physical Activity, 6*(3), 172–180. doi:10.1016/j.mhpa.2013.07.001

Petriwskyj, A., Thorpe, K., & Tayler, C. (2005). Trends in construction of transition to school in three western regions, 1990–2004. *International Journal of Early Years Education*, (13), 55–69.

Piaget, J., & Aebli, H. (1974). *Psychologie der Intelligenz* ((6. Aufl.)). Olten, Freiburg i.Br.: Walter.

Pirrie, A. M., & Lodewyk, K. R. (2012). Investigating links between moderate-to-vigorous physical activity and cognitive performance in elementary school students. *Mental Health and Physical Activity, 5*(1), 93–98. doi:10.1016/j.mhpa.2012.04.001

Ponitz, C. C., McClelland, M. M., Matthews, J. S., & Morrison, F. J. (2009). A structured observation of behavioral self-regulation and its contribution to kindergarten outcomes. *Developmental psychology, 45*(3), 605–619. doi:10.1037/a0015365

Pontifex, M. B., Saliba, B. J., Raine, L. B., Picchietti, D. L., & Hillman, C. H. (2013). Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder. *The Journal of pediatrics, 162*(3), 543–551. doi:10.1016/j.jpeds.2012.08.036

Preßler, A.-L., Könen, T., Hasselhorn, M., & Krajewski, K. (2014). Cognitive preconditions of early reading and spelling: a latent-variable approach with longitudinal data. *Reading and Writing, 27*(2), 383–406. doi:10.1007/s11145-013-9449-0

Rauch, W. A., Gawrilow, C., Schermelleh-Engel, K., & Schmitt, K. (2014). Dispositionelle Selbstkontrollkapazität bei Kindern: Erprobung einer Fremdbeurteilerversion der SCS-K-D. *Diagnostica, 60*(2), 61–72. doi:10.1026/0012-1924/a000099

Romine, C. B., & Reynolds, C. R. (2005). A model of the development of frontal lobe functioning: findings from a meta-analysis. *Applied Neuropsychology, 12*(4), 190–201. doi:10.1207/s15324826an1204_2

Rosenthal, R. S. L., & Jacobson, L. (1966). Teachers' expectancies: Determinates of pupils' IQ gains. *Psychological Reports, 19*, 115-118.

Roth, K., Ruf, K., Obinger, M., Mauer, S., Ahnert, J., Schneider, W., . . . Hebestreit, H. (2010). Is there a secular decline in motor skills in preschool children? *Scandinavian Journal of Medicine & Science in Sports, 20*(4), 670–678. doi:10.1111/j.1600-0838.2009.00982.x

Röthlisberger, M., Neuenschwander, R., Cimeli, P., & Roebers, C. M. (2013). Executive Functions in 5- to 8-Year Olds: Developmental Changes and Relationship to Academic Achievement. *Journal of Educational and Developmental Psychology, 3*(2). doi:10.5539/jedp.v3n2p153

Serrien, D. J., Ivry, R. B., & Swinnen, S. P. (2007). The missing link between action and cognition. *Progress in neurobiology, 82*(2), 95–107. doi:10.1016/j.pneurobio.2007.02.003

Sharp, C., van Goozen, S., & Goodyer, I. (2006). Children's subjective emotional reactivity to affective pictures: gender differences and their antisocial correlates in an unselected sample of 7-11-year-olds. *Journal of child psychology and psychiatry, and allied disciplines, 47*(2), 143–150. doi:10.1111/j.1469-7610.2005.01464.x

Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: a meta-analysis. *Pediatric Exercise Science, 15,* 234–256.

Stein, M. (2016). *Die Wirksamkeit chronischer und akuter sportlicher Aktivität auf die kognitiven Fähigkeiten von Vorschulkindern [Effectiveness of chronic and acute sports activities on preschooler's cognitive functions]* (Doctoral dissertation). Retrieved from http://nbn-resolving.de/urn:nbn:de:hebis:34-2016102651117

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643-662.

Suchodoletz, A. von, Trommsdorff, G., Heikamp, T., Wieber, F., & Gollwitzer, P. M. (2009). Transition to school: The role of kindergarten children's behavior regulation. *Learning and Individual Differences, 19*(4), 561–566. doi:10.1016/j.lindif.2009.07.006

Tangney, J. P., Baumeister, R. F., & Boone, A. L. (2004). High Self-Control Predicts Good Adjustment, Less Pathology, Better Grades, and Interpersonal Success. *Journal of Personality, 72*(2), 271–324. doi:10.1111/j.0022-3506.2004.00263.x

Thorell, L. B. (2007). Do delay aversion and executive function deficits make distinct contributions to the functional impact of ADHD symptoms? A study of early academic skill deficits. *Journal of child psychology and psychiatry, and allied disciplines, 48*(11), 1061–1070. doi:10.1111/j.1469-7610.2007.01777.x

Tomporowski, P. D., Lambourne, K., & Okumura, M. S. (2011). Physical activity interventions and children's mental function: An introduction and overview. *Preventive Medicine, 52, Supplement*(0), S3-S9. doi:10.1016/j.ypmed.2011.01.028

Tomporowski, P. D., McCullick, B., Pendleton, D. M., & Pesce, C. (2015). Exercise and children's cognition: The role of exercise characteristics and a place for metacognition. *Journal of Sport and Health Science, 4*(1), 47–55. doi:10.1016/j.jshs.2014.09.003

Ursache, A., Blair, C., & Raver, C. C. (2012). The promotion of self-regulation as a means of enhancing school readiness and early achievement in children at risk for school failure. *Child Development Perspectives, 6*(2), 122–128. doi:10.1111/j.1750-8606.2011.00209.x

van der Cammen-van Zijp, M. H. M., Ijsselstijn, H., Takken, T., Willemsen, S. P., Tibboel, D., Stam, H. J., & van den Berg-Emons, R. J. G. (2010). Exercise testing of pre-school children using the Bruce treadmill protocol: new reference values. *European journal of applied physiology, 108*(2), 393–399. doi:10.1007/s00421-009-1236-x

Verburgh, L., Konigs, M., Scherder, E. J. A., & Oosterlaan, J. (2014). Physical exercise and executive functions in preadolescent children, adolescents and young adults: a meta-analysis. *British Journal of Sports Medicine, 48*(12), 973–979. doi:10.1136/bjsports-2012-091441

Voelcker-Rehage, C. (2005). Der Zusammenhang zwischen motorischer und kognitiver Entwicklung im frühen Kindesalter – Ein Teilergebnis der MODALIS-Studie [The association between motor and cognitive development in early childhood – Partial results from the MODALIS-study]. *Deutsche Zeitschrift für Sportmedizin, 56* (10), 358–363.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625–636.

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., . . . Knecht, S. (2007). High impact running improves learning. *Neurobiology of learning and memory, 87*(4), 597–609. doi:10.1016/j.nlm.2006.11.003

World Health Organization. (1990). Specific developmental disorder of motor function. In *International statistical classification of diseases and related health problems* (10th ed.). Retrieved from http://apps.who.int/classifications/icd10/browse/2016/en#/F82

Zwicker, J. G., Missiuna, C., Harris, S. R., & Boyd, L. A. (2011). Brain activation associated with motor skill practice in children with developmental coordination disorder: an fMRI study. *International journal of developmental neuroscience : the official journal of the International Society for Developmental Neuroscience*, *29*(2), 145–152. doi:10.1016/j.ijdevneu.2010.12.002

Table 1

Descriptive and test statistics for the background and manipulation check variables of the two conditions

Variable	Control			Intervention			Diff	Total		
	n	*M*	*SD*	*n*	*M*	*SD*	*p*	*n*	*M*	*SD*
Sample characteristics										
Age [months]	52	67.94	12.78	51	69.08	13.18	.656[2]	103	68.50	12.93
Gender										
Female	25			22			.615[3]	47		
Male	27			29				56		
Body mass index	47	14.76	1.51	45	14.72	1.23	.909[1]	92	14.74	1.37
Motor coordination experiences	52	0.33	3.08	51	0.67	3.49	.556[2]	103	0.50	3.27
Self-control	51	43.42	9.16	51	43.76	8.41	.840[1]	102	43.59	8.74
Manipulation check										
Heart rate	34	101.05	12.18	37	127.30	10.61	.000[1]	71	114.73	17.39
Enjoyment	52	2.81	0.49	51	2.75	0.52	.440[2]	103	2.78	0.50
Perceived difficulty	52	1.46	0.64	51	1.84	0.64	.002[2]	103	1.65	0.67
Perceived exhaustion	52	1.33	0.51	51	2.10	0.78	.000[2]	103	1.71	0.76
Motivation to repeat	52	2.46	0.78	51	2.16	0.83	.048[2]	103	2.31	0.82
Affect										
Valence pre-post	52	0.21	0.67	51	-0.04	0.85	.270[2]	103	0.09	0.77
Arousal pre-post	51	0.08	0.69	51	-0.04	1.18	.479[2]	102	0.02	0.96

Note. [1]t-test, [2] Mann-Whitney-U test, [3] Chi[2]-test; in bold if $p < 0.05$.

Table 2

Regression analyses: Predicting executive functions performance

	n	*B*	*SE(B)*	β	*t*	*p*	*F*	*df*	*p*	*adj.R²*	*ΔR²*
Head-Toes-Knees-Shoulder task											
Overall model	99						12.87	6,92	<.001	.42	
Age		0.70	0.09	0.60	7.62	<.001					
Gender		4.87	2.40	0.16	2.03	.045					
Self-control		0.12	0.14	0.07	0.86	.393					
Condition		-2.10	2.30	-0.07	-0.91	.364					
Motor coordination experiences		-0.95	0.55	-0.21	-1.74	.085					
Condition*Motor coordination experiences		1.93	0.74	0.31	2.60	.011					.04
Day-Night-Stroop like task											
Overall model	102						5.12	6,95	<.001	.20	
Age		0.68	0.17	0.37	4.07	<.001					
Gender		4.21	4.39	0.09	0.96	.340					
Self-control		0.44	0.25	0.16	1.72	.089					
Condition		-7.43	4.23	-0.16	-1.76	.082					
Motor coordination experiences		-0.01	0.99	-0.01	-0.01	.989					
Condition*Motor coordination experiences		1.15	1.34	0.12	0.86	.393					.005

Note. Age, self-control and motor coordination experiences are centered at the grand mean; dummy-coded variables: gender with boys: 0, girls: 1, condition with control: 0, intervention: 1, in bold if $p < 0.05$.

Table 3

Simple slope analyses: Conditional effects of the condition on HTKS performance depending on the level of motor coordination experiences

Motor coordination experiences	unstand. Coeff.	*t*	*p*
Low level (- 1 SD)	-8.17	-2.49	.015
Moderate level (mean)	-1.91	-0.83	.409
High level (+ 1SD)	4.36	1.29	.199

Note. HTKS: Head-Toes-Knees-Shoulders task, condition is dummy-coded with control: 0, intervention: 1; in bold if $p \leq .05$

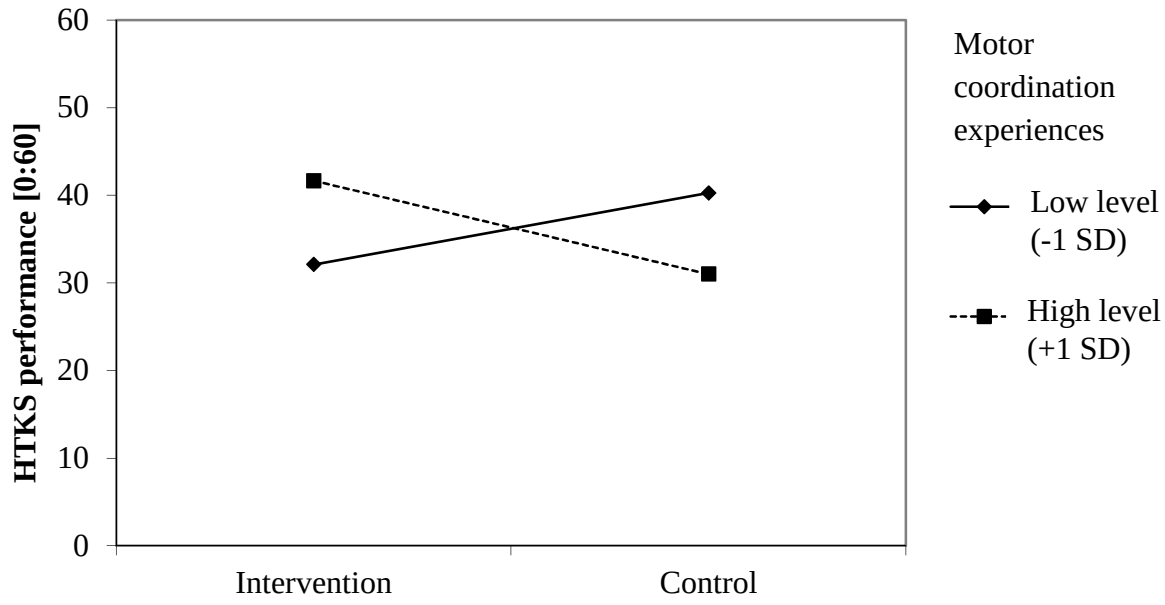

Figure 1. The level of motor coordination experiences moderates the effect of condition (intervention vs. control) on executive function performance in the Head-Toes-Knees-Shoulder task.

Appendix A

Assessment of motor coordination experiences with the questionnaire of physical activity in preschool children (Bayer et al., 2012)

(1) Do you or other persons take your child for swimming?

(2) How often does your child climb on trees, wall bars or similar?

(3) How often does your child play with a ball?

(4) How often does your child play tag?

(5) How often does your child ride a bike or use a kick scooter?

(6) How often does your child skate (roller skates, inline skates)?

(7) Does your child attend a sports club or sports group?