# Physical activity and developmental psychopathology in children and adolescents: cross-sectional, longitudinal follow-up and concurrent developmental relationships

Dissertation

zur Erlangung des humanwissenschaftlichen Doktorgrades

in der Medizin

der Georg-August-Universität Göttingen

vorgelegt von

Parisa Ganjeh

aus Khuzestan, Iran

Göttingen, 2023

## Thesis Committee

**Prof. Dr. Aribert Rothenberger (Supervisor)**
Clinic for Child and Adolescent Psychiatry and Psychotherapy, University Medical Center Goettingen

**Prof. Dr. York Hagmayer**
Department of Cognitive Science and Decision Psychology, Georg-Elias-Müller-Institute for Psychology, University of Goettingen

**Prof. Dr. Nicole von Steinbüchel**
Institute of Medical Psychology and Medical Sociology, University Medical Center Goettingen

## Members of the Examination Board

**Referee: Prof. Dr. Aribert Rothenberger**

**2nd Referee: Prof. Dr. York Hagmayer**

**3rd Referee: PD. Dr. Claudia Bartels**

## Further members of the Examination Board

**Prof. Dr. Nicole von Steinbüchel**
Institute of Medical Psychology and Medical Sociology, University Medical Center Goettingen

**Prof. Dr. mult. Thomas Meyer**
Clinic for Psychosomatic Medicine and Psychotherapy, German Centre for Cardiovascular Research, University Medical Center Goettingen

**PD. Dr. Claudia Bartels**
Clinic for Psychiatry and Psychotherapy, University Medical Center Goettingen

**Prof. Dr. Hannes Rakoczy**
Department of Developmental Psychology, Georg-Elias-Müller Institute for Psychology, University of Goettingen

**Prof. Dr. Jens Wiltfang**
Department of Psychiatry and Psychotherapy, University Medical Center Goettingen

**Date of oral examination: 07.07.2023**

# Statement of Originality

I hereby declare that the following thesis “Physical activity and developmental psychopathology in children and adolescents: cross-sectional, longitudinal follow-up and concurrent developmental relationships” was independently written and with no other sources and aids than quoted in the text, references and acknowledgments.

Göttingen, May, 2023

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# Chapter 1 – Introduction

One of the primary goals of research in mental health, particularly in children and adolescents, is to develop effective prevention and treatment programs for mental health problems (MHP) that are also low-risk, inexpensive, and non-invasive. Physical activity (PA) has been shown in empirical studies to provide some benefits for children and adolescents with mental health problems (Andermo et al., 2020; Carter et al., 2021; Heinze et al., 2021; Liang et al., 2021; Vella et al., 2019; Wolf et al., 2021; Yang et al., 2021). However, so far, no conclusion has been reached due to the heterogeneity of methodology, measuring of outcomes, quality and risk of bias (Biddle et al., 2019; Dhir et al., 2021; Lambez et al., 2020; Ruhland & Lange, 2021; Seiffer et al., 2022; Welsch et al., 2021). Also, there exist some contradictory findings (Carson et al., 2017; Gómez-Baya et al., 2020; Hinkley et al., 2014; Hinkley et al., 2017; Nigg et al., 2021; O'Brien et al., 2020). Hence, more research is needed in order to better clarify the issue.

Studying in this PhD thesis the cross-sectional, longitudinal follow-up, and concurrent developmental relationships between PA and general mental health problems as well as ADHD symptoms in different age groups and genders may expand and deepen our knowledge by adding new evidence and estimating cause-effect relationships. Hopefully, this allows researchers to derive recommendations with respect to how PA may be beneficial for preventing and treating mental health problems (including ADHD symptoms) in children and adolescents.

## 1.1 Mental Health Problems

### 1.1.1 Mental Health Problems in Children and Adolescents

Mental health is defined as a spectrum of good to poor mental, emotional, social, and behavioral competence (Bitsko et al., 2022). Mental health problems like, depression, anxiety, and behavioral disorders are major causes of disease and disability in young individuals (World Health Organization, 2022). Children with mental health conditions are believed to show problems resulting from how they think, behave, interact with others, make decisions, or manage their emotions (Center for Disease Control and Prevention, 2022).

Around the world, about 10% of children and adolescents are suffering from a mental condition (World Health Organization, 2022). According to a systematic review and meta-analysis, the total prevalence of any childhood mental issue (in 4-18 years olds) in high-income countries was 12.7% (Barican et al., 2022). The German Robert Koch Institute reported that between 2003 and 2007,

20% of children and adolescents displayed symptoms of mental health issues in Germany, while 17% did so between 2014 and 2017 (Klipker et al., 2018).

Mental health conditions, which have such a high prevalence, are the largest contributors to the general burden of disease worldwide (Renwick et al., 2022), and they may have a negative impact on a person's social and academic skills, as well as their productivity, and they may also result in disabilities (Erskine et al., 2015; World Health Organization, 2022). Unfortunately, a large proportion of children and adolescents who suffer from mental health problems do not seek help or treatment (World Health Organization, 2022). Even in countries with high levels of income, only 44.2% of those affected by these problems receive any type of therapy or services (Barican et al., 2022). For these reasons, additional research, particularly in an epidemiological setting, is necessary in order to improve the mental health of children and adolescents.

### 1.1.2 Attention-Deficit Hyperactivity Disorder (ADHD) Symptoms

Neurodevelopmental disorders are chronic conditions with a functional impact. These disorders are related (at least partly) to changes in the brain and/or the neuromuscular system. Disorders of the autistic spectrum, attention-deficit hyperactivity disorder, tic disorders and developmental speech/language disorders are some examples of these types of conditions (Ogundele & Morton, 2022). ADHD is the most frequent one with important negative psychosocial consequences (Coghill et al., 2021). ADHD is characterized by persistent, age-inappropriate, and severe inattentive/disorganized and/or hyperactive/impulsive behaviors that continue for at least 6 months (American Psychiatric Association, 2016). For a broad and deep overview on ADHD see the recent book in German language by Steinhausen et al., (2020).

ADHD is present in about 5% of individuals worldwide (Posner et al., 2020), and can affect children and adolescents to the extent of 7.2% (Thomas et al., 2015). The prevalence rates for ADHD among children and adolescents in Germany were 5.3% between the years 2003 and 2006 and 4.4% between the years 2014 and 2017 respectively (Göbel et al., 2018). Individuals who have ADHD are more likely to struggle in a variety of domains, including academics, interpersonal relationships, and occupational and social functioning. They also have a higher risk of co-occurring with other mental illnesses (American Psychiatric Association, 2016; Erskine et al., 2016; Lambez et al., 2020). The economic impact of ADHD among children in the United States was reported to be $19.4 billion ($6,799 per child) and among adolescents it was reported to be $13.8 billion

($8,349 per adolescent) (Schein et al., 2022). These figures include both direct and indirect annual expenditures. It has been determined that the expense of bringing up a child with ADHD until puberty is five times the cost of bringing up a child who does not have this disease (Zhao et al., 2019). Given these long-term negative effects (Banaschewski et al., 2017) as well as the fact that currently available treatments for ADHD (such as behavior therapy and/or medication) are unable to address all issues (Rommel et al., 2015; Vysniauske et al., 2020; Welsch et al., 2021), complementary and additional strategies need to be found.

### 1.1.3 Development of Mental Health Problems

The majority of mental conditions have their origins in childhood (Nees et al., 2021). The early years of childhood and adolescence are crucial for mental health development (World Health Organization, 2022). The onset of symptoms at an early age has been linked to increased burden and chronification (Perra et al., 2020). To put this into perspective, it is estimated that approximately 45% of people who develop mental problems as young adults had a traumatic or negative childhood experience (Green et al., 2010).

The characteristics of mental health problems in childhood and adolescence include internalizing (anxiety disorders, depressive disorders) and externalizing problems including conduct disorders and ADHD (Bains & Gutman, 2021). Anxiety disorders (up to 31.9%), behavior disorders (16.3-19.1%), substance use disorders (8.3-11.4%), emotional disorders (3.7-14.3%), hyperkinetic disorders (2.2-8.6%), and aggressive dissocial disorders (2.1-7.6%) are the most prevalent in children and adolescents (Fuchs et al., 2013). The prevalence of children's internalizing difficulties increases as they enter adolescence (Costello et al., 2011), reaches its peak in early adulthood (ages 20-24 years) (Beauchamp et al., 2018). By contrast, externalizing issues typically become less prevalent during development (Costello et al., 2011; Miner & Clarke-Stewart, 2008).

The majority of children's emotional and behavioral problems are said to remain stable throughout childhood (Flouri et al., 2018). However as children get older, they show obvious indications of mental distress. For example, between the ages of 11 and 14, they are at an increased risk for experiencing problems related to their mental health (Yoon et al., 2022). There are also gender differences associated with a number of disorders, and the development and progression of mental health problems over the course of a person's lifetime can vary significantly from person

to person (Meyrose et al., 2018); i. e. different individual trajectories have to be taken into account. In general, boys have two times as many mental health problems as girls do (2:1), but girls have a higher prevalence rate after the age of 13 years (Ihle & Esser, 2002). For instance, while the prevalence of substance use disorders is comparable between the genders, both boys and girls have significantly greater rates of behavior disorders, as well as mood and anxiety disorders, respectively. Anxiety states often begin in childhood, in contrast to conduct disorder and mood difficulties, which typically emerge during the early and later stages of adolescence (Merikangas et al., 2009; Yoon et al., 2022). Studies have indicated that there are gender-specific differences in the progression of mental health problems, with boys showing a decline whereas girls did not demonstrate this trend at all (Meyrose et al., 2018). Mental health problems and subjective wellbeing trajectories of 8612 young people were investigated over the course of time between the ages of 11/12 and 13/14 (Yoon et al., 2022). Girls experienced a higher amount of emotional difficulty than males did when they were 11–12 years old, and the difference between the two genders continued to widen after that point. The subjective wellbeing of girls was slightly but significantly lower than that of boys between the ages of 11 and 12, and it continued to decline through time, whereas the wellbeing level of boys remained largely stable (Yoon et al., 2022).

Other factors, besides gender, also seem to have an influence on the development of problems with mental health in children and adolescents. Low socioeconomic status, stressful life events, conduct problems, and substance use were the characteristics that were most frequently shown to differentiate between high and increasing depressive symptom trajectories versus other trajectories in a comprehensive review and meta-analysis (Shore et al., 2018). Further biopsychosocial factors that may explain different trajectories include genetics, early attachment problems that make children more vulnerable to stressors, the development of poor coping mechanisms, including substance abuse and maladaptive behavior, and a lack of parental and peer support (see Shore et al., 2018 for references).

Findings from a different study also indicated that a variety of factors, such as child sex, maternal mental health, socioeconomic status (family income, maternal education, and neighborhood disadvantage), hostile parenting, and child temperament, have an impact on children's mental health at the age of four (persistence, sociability, reactivity) (Christensen et al., 2017). Thus, these elements have an impact on children's mental health at a critical time before they start school (Christensen et al., 2017). Also, sex, sociability, parental warmth, sports

engagement, and household wealth were found to be important predictors of distinct mental health trajectories that the trajectory with the highest prevalence is the low difficulty trajectory (Vella et al., 2019). A unique predictor of overall risk for mental health disorders in children is participation in organized sports, which is also linked to decreased risk trajectories (Vella et al., 2019).

### 1.1.4 Development of ADHD Symptoms

The typical onset of ADHD symptoms is before age 6, but they must start before age 12 for assigning an ADHD diagnosis (American Psychiatric Association, 2016). This neurodevelopmental disorder can last into adulthood with developmental changes to its main characteristics. For example, levels of hyperactivity-impulsivity symptoms decline with age, but inattention symptoms of ADHD reflect less of an age-related reduction. The DSM-5 has now lowered the number of ADHD symptoms necessary for an adolescent and adult diagnosis of ADHD in acknowledgment of this developmental change (Thapar & Riglin, 2020).

The prevalence of ADHD symptoms declines from childhood through middle age (Wootton et al., 2022), whereas the age-related fall in inattention issues is less pronounced (Thapar & Riglin, 2020). In general, 5-15% of people still match the diagnostic requirements for ADHD as adults (Banaschewski et al., 2017). This overall pattern of declining features across development is in line with findings from clinical samples collected over the course of the lifespan and single cohort studies across childhood and adolescence (Wootton et al., 2022). Results from five birth cohort studies in the population, ranging in age from 3 to 45 years, revealed that generally, boys not only scored higher on average than girls, in clinical and population samples, but they also showed a steeper decrease in symptoms (Wootton et al., 2022). However, the development of ADHD symptoms can be quite variable (Asherson & Agnew-Blais, 2019). It is unclear if there are sex differences in the developmental trajectories of ADHD that are significant. While some research has claimed that there are no gender differences, others have suggested that females may be more likely to experience a later onset, particularly around puberty (Murray et al., 2019). For example, Döpfner et al. (2015) investigated the development of ADHD symptoms in 7 to 19-year-olds. They discovered that among trajectory groups with high levels of ADHD symptoms, boys were considerably overrepresented. But research did not identify any differences between sexes concerning the age at which symptoms first appeared or peaked (Döpfner et al., 2015). Further, boys were more likely to have higher symptoms from childhood on, in a cohort study with 1,571 participants from elementary and secondary schools, while girls were more likely to have

significant symptom increases in early adolescence (Murray et al., 2019). The latter is a sensitive developmental period for both boys and girls, marked by very dramatic symptom increases (Murray et al., 2019).

The development of ADHD symptoms can be influenced by a variety of variables and factors. It is important to differentiate between various ADHD symptom trajectories by considering factors such as gender, behavior problems, cognitive ability, mother's education, preterm delivery, peer problems, and school readiness scores (Murray et al., 2021). In another study, findings suggested that the persistence of ADHD symptoms may be influenced by perceptions of parental rejection (Brinksma et al., 2021). PA has also been demonstrated not only as a lifestyle factor linked to reduced ADHD symptoms (Loewen et al., 2020), but also as a viable intervention for children and adolescents suffering from ADHD (Seiffer et al., 2022). But, so far, firm conclusions cannot be drawn and there is still a need for further investigations to better understand the relationship between PA and ADHD.

## 1.2 Physical Activity (PA)

The WHO defined "physical activity as any bodily movement produced by skeletal muscles that requires energy expenditure and can be performed at a variety of intensities, as part of work, domestic chores, transportation or during leisure time, or when participating in exercise or sports activities" (World Health Organization, 2020). In all ages, PA is necessary. Both early childhood development and healthy growth and development in children and adolescents are affected by active play and recreation (World Health Organization, 2018). PA gives advantages for a variety of health outcomes in children and adolescents, including cardiorespiratory, cardiometabolic health (blood pressure, dyslipidemia, glucose, and insulin resistance), and mental health (World Health Organization, 2020).

The WHO recommended that "Children and adolescents should do at least an average of 60 minutes per day of moderate to vigorous-intensity, mostly aerobic, physical activity, across the week" (World Health Organization, 2020). However, the WHO's global recommendations for PA are not currently being met by 1 in 4 people and 3 in 4 teenagers (ages 11 to 17) worldwide. Inactivity levels rise when economies develop in a country. Due to shifting mobility patterns, rising technology use, and urbanization, levels of inactivity can reach up to 70% in some countries (World Health Organization, 2018). In 2013, the annual direct health care expenses associated with this

rate of physical inactivity were estimated to be over INT$ (international dollar) 54 billion, with a further INT$ 14 billion related to lost productivity. Costs related to mental health and musculoskeletal disorders are not included in the 1-3% of national health care expenses that are attributable to inactivity. With a goal of encouraging more people to be physically active for a healthier world, the WHO has a worldwide action plan on PA between 2018 and 2030. By 2030, the plan's goal is to have a 15% relative decrease in the prevalence of physical inactivity among adults and adolescents worldwide (World Health Organization, 2018).

### 1.2.1 Development of Physical Activity

Recent research from the International Children's Accelerometry Database (ICAD), a global data-sharing initiative, has shown that mean values for both moderate to vigorous PA (MVPA) and total volume of PA both appear to gradually decline after the age of five (Cooper et al., 2015). In addition, the decline in PA that occurs during the transitional period from childhood to adolescence has been highlighted by research and systematic reviews (Farooq et al., 2020; Reilly, 2016). To give an example, Pate et al. discovered that children between the ages of 10 and 14 experienced a relatively steep age-related decline in total PA, with a slower rate after that age (Pate et al., 2022). These findings were consistent with those of another study, which found that when data were compared year to year, the level of PA among children aged 7 to 10 years had not changed considerably; but at the age of 10, authors observed a substantial decline in PA scores, which continued to decline (de Araújo et al., 2018). Whether or not this might be related to the transition from elementary school to classes with higher cognitive and behavioral (sitting) demands, remains an open issue. Additionally, a review of 23 studies on the long-term patterns of PA revealed that participation in PA is likely to decrease during adolescence. This analysis revealed that depending on the type of PA, the trajectory of PA varied across the 27,231 participants. The majority of studies on active transportation found that activity increased during childhood, remained stable during the transition to adolescent, and remained stable or even decreased during adolescence. The majority of research on so called organized PA found that there was an increase throughout childhood, a rising or stable trend in the period leading up to adolescence, and no change or drop during this time. Participation in non-organized PA appeared to decline among adolescent boys while remaining consistent among adolescent girls. During the transition to adolescence, active chores did rise before stabilizing (Kemp et al., 2019).

The level and trajectory of PA are influenced by sex. According to studies, not only are boys more likely to be physically active than girls (de Araújo et al., 2018; Ng et al., 2020; Pate et al., 2022), but girls also have a higher age-related rate of decrease (Farooq et al., 2020; Pate et al., 2022). However, inconsistent findings suggest that decreases in PA were not noticeably more pronounced in girls than in boys (Farooq et al., 2018; Reilly, 2016). Therefore, additional research is needed to provide a clearer picture of how gender influences PA development, especially when studies focus on subgroups who do not conform to the state of the art. One group of boys with significantly high MVPA that remained consistent between the ages of 7 and 15 years was described in a cohort study (Farooq et al., 2018). Other studies also demonstrated high PA trajectories in children and adolescents (Aira et al., 2021; Lounassalo et al., 2019).

The WHO advised that participating in some PA is preferable to doing none because of the advantages of being active. Beginning with small quantities of PA, children and teenagers should gradually increase their frequency, intensity, and duration over time (World Health Organization, 2020). To the best of our knowledge, there exist only few and inconclusive studies looking at concurrent trajectories of mental health issues, ADHD symptoms, and PA although the latter is a modifying factor to mental health problems in children and adolescents. Hence, it is essential to study developmental trajectories in order to develop fruitful suggestions how to handle PA on a day-by-day basis.

## 1.3 Relationship between General Mental Health Problems as well as ADHD Symptoms with Physical Activity

### 1.3.1 Cross-sectional and Longitudinal Relationship between General Mental Health Problems and Physical Activity

Studies have shown that PA improves mental health in children and adolescents. Young people's cognitive and mental health are reportedly impacted by PA through neurobiological, psychological, and behavioral mechanisms (Lubans et al., 2016). Most research documents improvements in mental health and cognition after longer-term PA interventions that also coincide with neurobiological changes, particularly changes in frontal region electrical parameters and activation observed neuroimaging investigations (Heinze et al., 2021). The release of norepinephrine and endorphins, increased blood supply to the brain, and good effects on brain structure and function may all contribute to improved mental health as stress levels decrease and cognitive functioning and

mood improve (Rodriguez-Ayllon et al., 2019; Spruit et al., 2016). Young people's physical self-concept, autonomy, competence, relatedness, and perceived competence are only a few psychosocial pathways that may influence the benefits of PA on mental health (Doré et al., 2020; Lubans et al., 2016). Last but not least, a variety of possible behaviors, such as sleep length, sleep efficiency, sleep onset delay, and decreased fatigue, may contribute to the influence of PA on mental health outcomes (Lubans et al., 2016).

Studies revealed a favorable impact of PA on behavior, balance, flexibility, self-concept, self-efficacy (Wilson & Barnett, 2020), resilience, positive mental health, well-being (Andermo et al., 2020), perceived school performance (Ng et al., 2020), happiness (van Woudenberg et al., 2020), and health-related quality of life (Wu et al., 2017). The impact of PA on mental health problems has been reported in cross-sectional, longitudinal, systematic reviews and meta-analysis researches. Reduced sports engagement and lower PA were both correlated with increased emotional symptoms (Sampasa-Kanyinga et al., 2020; Vella et al., 2019). In children and adolescents, higher levels of PA were linked to lowered probabilities or symptoms of depression and anxiety (Bélair et al., 2018; Carter et al., 2021; Kandola et al., 2020; Ma et al., 2020; Schuch et al., 2019). A systematic review during the Covid-19 pandemic revealed lower depression and anxiety among people who engaged in regular PA more frequently (Wolf et al., 2021). In longitudinal assessments of the relationship between PA and mental health problems occurring 3 to 10 years later, higher levels of PA were associated with fewer internalizing/externalizing symptoms (Isaksson et al., 2020; Wu et al., 2021). Despite these positive effects of PA on mental health problems, outcomes are inconsistent, and some conflicting results have been recorded. Although the authors of a study found that more active adolescents had higher slopes of depressive symptoms at the start of the procedure, they also found that after two years, these adolescents had fewer depressed symptoms than those who had lower PA at baseline (Gómez-Baya et al., 2020). No significant relationship was found between PA and the incidence of psychological issues among early school-aged children (Hinkley et al., 2017; O'Brien et al., 2020; Rodriguez-Ayllon et al., 2019). Additionally, there was no association between PA and later antidepressant usage in adolescents (Kleppang et al., 2019), and the total difficulty of mental health problems (Bell et al., 2019). These results are consistent with a longitudinal study, which revealed that in this age group, PA may not be a preventative factor for mental health issues (Nigg et al., 2021). Even other studies found that PA had the inverse effect on mental health, with higher levels of PA being related to higher mental health problems (Hartman et al., 2019) and conduct

problems (only among boys) (Ahn et al., 2018). Hence, differentiation of PA effects by gender, age of implementation, duration, intensity etc. seems to be rectified.

### 1.3.2 Cross-sectional and Longitudinal Relationship between ADHD Symptoms and Physical Activity

The recommended strategy of treating ADHD differs depending on age, so that for preschoolers, behavior therapy (e.g. applied after training by a parent or teacher) is the most frequently suggested treatment. While medicine is the primary line of treatment for school-age children and adolescents (Wolraich et al., 2019). When behavior therapy is ineffective, undesirable, or acute problems require an immediate intervention, medication is advised in a German guideline for ADHD in children and adolescents (Banaschewski et al., 2018). Since conventional treatments cannot completely address the full spectrum of problems (Swanson et al., 2001), and psychopharmacological treatments may have side effects (Banaschewski et al., 2018; Clavenna & Bonati, 2014), it is important to explore for alternative and/or supplemental interventions (Rommel et al., 2015; Vysniauske et al., 2020; Welsch et al., 2021). PA as one of the lifestyle recommendations for ADHD (Loewen et al., 2020), is a potential alternative and/or supplementary therapeutic and protective factor for children with ADHD (Lange, 2020). Positive effects of physical exercise on cognitive difficulties of ADHD were reported with a higher effect size (Morris d=0.93) than neurofeedback, cognitive-behavioral treatment, and cognitive training in a systematic review and meta-analysis of 19 chosen studies in children (Lambez et al., 2020); but selection of studies and their methodological quality do not allow generalization.

It seems that PA helps to decrease the symptoms of ADHD through its impact on executive and cognitive functioning. Exercise interventions have been shown to improve all executive functions (inhibitory control, cognitive flexibility, working memory, and shifting memory) in ADHD children and adolescents, according to systematic reviews and meta-analyses (Liang et al., 2021; Welsch et al., 2021). Short-duration activities and a 1-hour PA were found to have positive impacts on attention and on-task behavior (Ruhland & Lange, 2021). Additionally, longer exercise sessions were linked to improved executive functioning and motor results in the management of ADHD (Vysniauske et al., 2020). A recent study found that when PA was combined with cognitive tasks, executive functions and behavioral symptoms in children with ADHD were improved even after 1 month of follow-up (Nejati & Derakhshan, 2021). Furthermore, it has been demonstrated that PA can aid children with ADHD by reducing their social and emotional difficulties, aggressive

behaviors, and anxiety and depression symptoms (Zang, 2019). In school environment, also teacher-reported data showed a decrease in ADHD symptoms after an intervention study (Taylor et al., 2019).

According to longitudinal research, only girls who consistently participate in organized sport between the ages of 6 and 10 had lower levels of ADHD symptoms by the age of 12 (Pagani et al., 2020). Activities during adolescence were also discovered to be strongly associated with decreased levels of ADHD symptoms during the early stages of adulthood among a population sample of monozygotic twins (Rommel et al., 2015). However, according to a small number of longitudinal studies, inconsistent findings of the association between PA and ADHD symptoms were also documented (Smith et al., 2019; Vella et al., 2017). In both a 3-year follow-up study of adolescents and a prospective study, PA was not linked to ADHD symptoms or behavioral issues (Isaksson et al., 2020; Peralta et al., 2018). In comparison to diet, PA, and screen time as multiple lifestyle factors in school-aged children, Hong et al. found that only sleep quality was significantly different between children with and without ADHD (Hong et al., 2021). Furthermore, more PA may be even linked to increased ADHD symptoms over time (Brandt et al., 2021; Wiles et al., 2008), and objectively measured PA of any intensity was linked to higher hyperactivity scores in both boys and girls (Griffiths et al., 2016). Hence, also the relationship between PA and ADHD symptoms deserves further and better clarification.

# Chapter 2 – The Cumulative Dissertation

## 2.1 Aims of the Cumulative Dissertation

In light of the research presented in the previous chapter, the current cumulative dissertation aimed to investigate the cross-sectional and longitudinal relationships between mental health problems, including symptoms of ADHD, and PA in children and adolescents. Using data from the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) (Hölling et al., 2012) had the benefit of a large population sample (17640 participants) of children and adolescents from 0 to 17 years old investigated across a 10-year period. The dissertation aimed to shed additional light on the association between mental health problems and PA by addressing the following research questions: (a) whether there exists a cross-sectional relationship between general mental health problems as well as ADHD symptoms and PA in different age groups. If so, (b) whether there exists a longitudinal association between them over a 10-year period, and (c) how developmental trajectories of general mental health problems as well as ADHD symptoms, are related to those of PA. These questions led us to three separate studies.

The first study looked cross-sectionally into the relationship between PA and general mental health problems as well as ADHD in children and adolescents of various ages. Three distinct developmental age groups were examined independently at each of the three KiGGS time points: preschoolers aged 4-5, elementary school students aged 6-9, and teenagers aged 10-17. These age ranges were chosen based on several psychosocial developmental factors and the difficulties these age ranges confront. In preschool-age children, the psychosocial developmental factors and requirements focus on developing basic trust and autonomy. Children at this stage need to feel safe and secure in their environment, and they require a nurturing and predictable routine that fosters a sense of predictability and routine. They also need to develop a sense of autonomy and independence, which is supported by allowing them to make choices and explore their surroundings in a safe and supportive manner (Berk, 2018).

School-age children face a different set of psychosocial developmental factors and requirements. At this stage, they begin to develop a sense of competence, as they learn new skills and take on more responsibility. They also begin to develop their social relationships, forming close friendships and learning how to navigate complex social interactions. In order to support their

development, school-age children need opportunities to explore their interests and passions, as well as guidance and support from adults and peers (Berk, 2018).

During adolescence, psychosocial developmental factors and requirements focus on identity formation and establishing meaningful social relationships. Adolescents are going through a period of intense physical and emotional changes, and they are grappling with issues such as self-identity, peer pressure, and social norms. They require a safe and supportive environment that allows them to explore and experiment with different identities and social roles, while also providing them with guidance and support from trusted adults. Additionally, adolescents need opportunities to develop meaningful relationships with peers and adults who share their interests and values, as well as opportunities to participate in meaningful activities that help them build their self-esteem and sense of purpose (Berk, 2018).

Additionally, in this study, we investigated whether the clinical diagnosis of ADHD (as compared to non-ADHD controls) may moderate the relationship between various PA levels and mental health problems in diverse age groups. Therefore, we compared a model with an interaction term to a model without the interaction term in order to investigate any interactions between frequency levels of PA and the parent-reported diagnosis of ADHD (ADHD vs. controls) with regard to the overall SDQ score representing general mental health problems in the study. In order to control for potentially confounding factors, we also used the individuals' sex, age, and body mass index (BMI) as well as parental socioeconomic (SES) level in the analysis.

In the second study, we aimed to investigate the longitudinal relationships between PA in childhood and adolescence with general mental health problems as well as symptoms of ADHD. Two variables (PA and general mental health using the total SDQ score or PA and ADHD symptoms using the SDQ-H/I subscale) were measured at three time points (Baseline, Wave 1, and Wave 2). We used an auto-regressive cross-lagged model to evaluate the longitudinal follow-up relationship (Figure 1). Two separate models were computed to find cross-lagged relationships between PA and general mental health as well as PA and ADHD symptoms. Using cross-lagged models for the statistical analysis, we were able to examine temporal and longitudinal impacts among variables while controlling for their concurrent connections and covariates such as SES as a time invariant covariate at Baseline and BMI as a time variant covariate across time-points. We also used sex as a grouping variable. The results show potential causality and the temporal precedence of cross-domain PA and mental health problems (including ADHD symptoms) in

childhood and adolescence. Cross-sectional studies do not provide temporal effects and experimental studies are not possible. It is unethical to include a control group with very low levels or even with no PA for a long period of time in a controlled randomized trial.

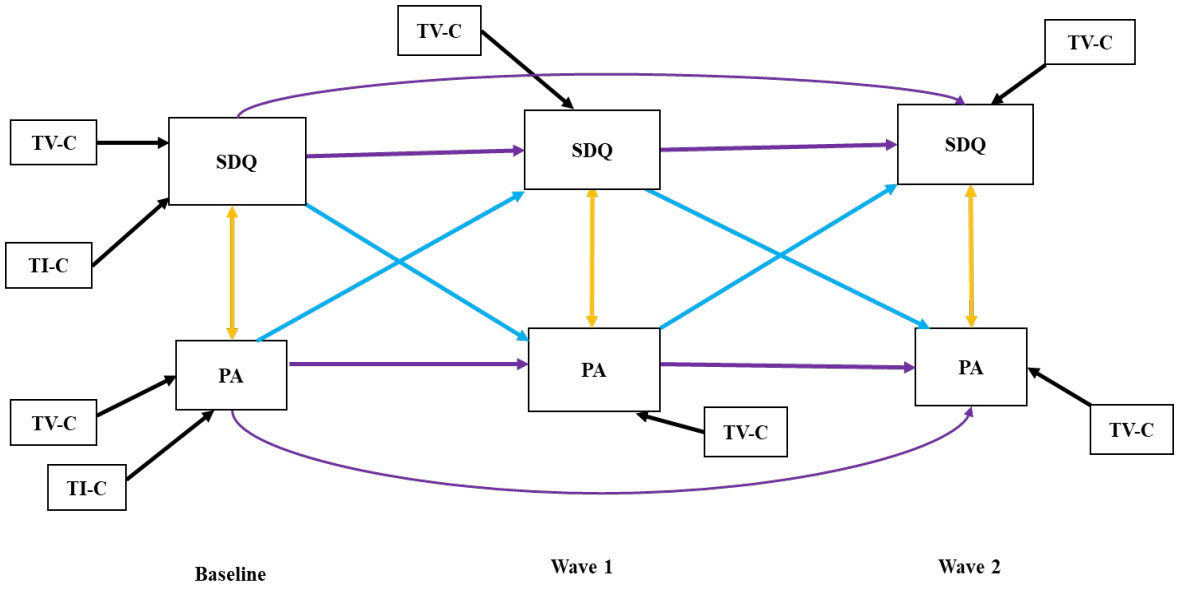


Figure 1. Auto-regressive Cross-lagged model
TV-C: Time-variant covariate, TI-C: Time-invariant covariate, Purple arrows: Auto-regressive paths, Blue arrows: Cross-lagged arrows, Yellow arrows: Cross-sectional paths, Black arrows: Covariate paths, SDQ: Indicating SDQ-Total for the first model as well as SDQ-H/I for the second model at Baseline, Wave 1, and Wave 2, respectively

In the third study, our objective was to investigate the concurrent developmental trajectories of mental health problems (both in a general sense and more specifically, symptoms of ADHD) and PA in boys and girls. In this work, we first used latent class mixed models (LCMM) to discover latent classes of trajectories for each variable. Next, we analyzed the joint probability distribution of distinct classes of trajectories of general mental health problems and ADHD symptoms and of PA. Simply put, we investigated the relationship of trajectories of mental health and PA. The results will show us how PA can affect the development of mental health problems.

## 2.2 The KiGGS Study

The data from the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) were used in this cumulative dissertation to conduct statistical analyses addressing the research questions. The KiGGS study on the health of children and adolescents in Germany is part of the continuous and comprehensive health monitoring program established at the Robert Koch Institute (RKI, Berlin) in the Department of Epidemiology and Health Monitoring. The KiGGS

study was conducted at three time points. The KiGGS Baseline survey included an interview and examination survey between the years of 2003 and 2006. There was a participation of 17,640 children and adolescents who were between the ages of 0 and 17 years old as well as their parents. Participants came from one of 167 different study sites, and they were picked at random using a stratified selection procedure. In May 2009, six years after the KiGGS Baseline survey, the first wave of the KiGGS follow-up (KiGGS Wave 1) survey got underway. The completion of this telephone survey took place in June of 2012. In addition to new participants, the earlier respondents from the KiGGS Baseline survey, who were now between the ages of 6 and 24, were reinvited to participate. Interviews, examinations, and tests were a part of KiGGS Wave 2, which began in September 2014 and was structured in the same way as the Baseline survey. In this second follow-up survey, both new participants and those who had previously participated were included. The collection of data for KiGGS Wave 2 was finished in August of 2017.

The response rate for the Baseline survey was 66.6%, and 11,992 (or 68%) of the respondents from the Baseline survey took part in Wave 1. There were 5914 boys' participants and 6078 girl's participants (Mauz et al., 2019). In Wave 2, a cross-sectional and longitudinal sample of 15,023 children and adolescents ranging in age from 0 to 17 years was included. In the longitudinal sample, there were a total of 10,853 boy and girl participants at Wave 2, which equals a response rate of 61.5 percent (Kurth, 2018). Because this cumulative dissertation used SDQ parent-report data, which were only available up to the age of 17, we could only use longitudinal data from participants who were younger than 17 years old at all time points (see Figure 2) (Hofmann et al., 2018).

In each study of this cumulative work, participants' levels of PA were classified according to one of three categories (low, medium, and high). PA data were collected from the parents of children (0 to 10 years old) as well as teenagers (11–17 years old). The Strength and Difficulties Questionnaire (SDQ) total score, as reported by the parents, was used as an indicator of general mental health problems (SDQ-total score). The hyperactivity/inattention subscale (SDQ-H/I) was used as an indicator of symptoms of ADHD.

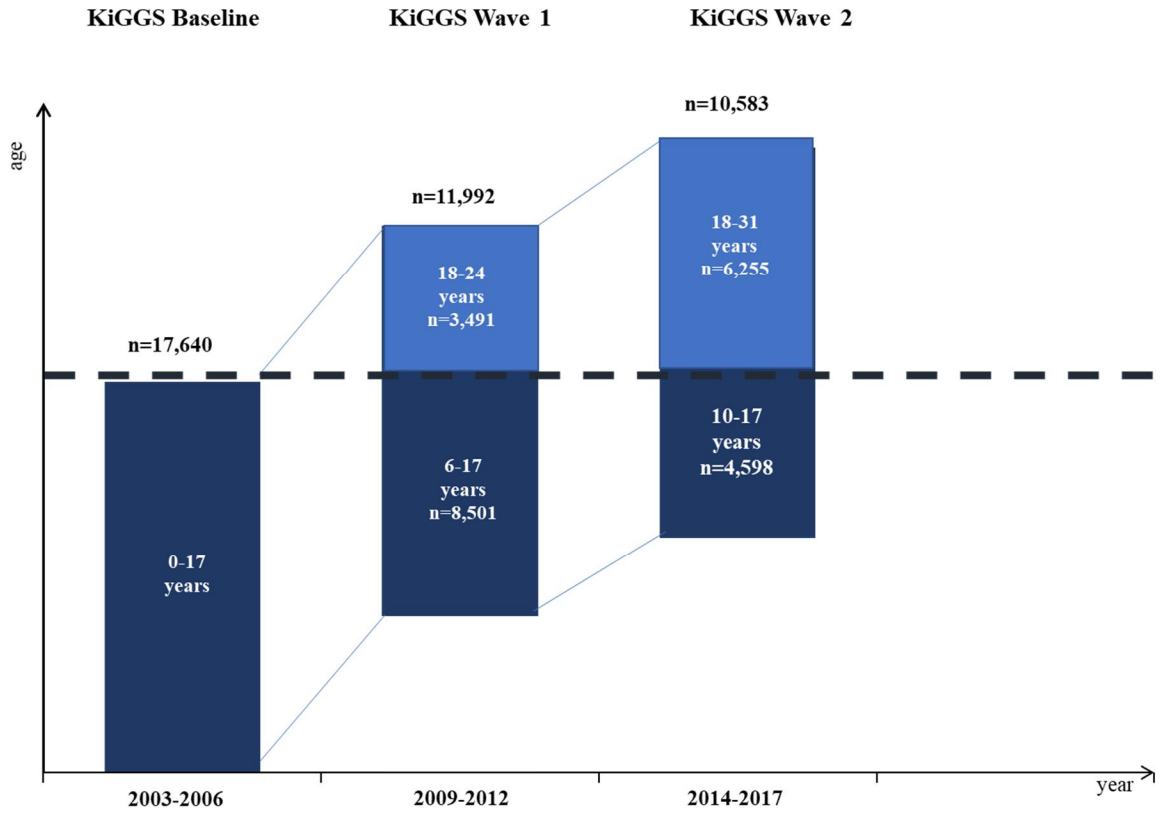


Figure 2. Longitudinal sample sizes of the KiGGS study
Dark blue bars: Longitudinal data up to 17 years old (the data used for analyses in the current study).
Light blue bars: Longitudinal data at Wave 1 and Wave 2 older than 17 years.

## 2.3 Methods

In the three studies of this dissertation, several statistical methodologies have been used. The following sections provide a rough introduction into the respective statistical models.

### 2.3.1 General Linear Model

In the fields of statistics, the general linear model (GLM) is one of the most widely used statistical model. Many common statistical tests like the T-test and the F-test build upon the general linear model. Other examples include simple linear regression, multiple linear regression, the analysis of variance, and the analysis of covariance (Ostwald, 2020). The standard GLM is based on the following four major assumptions: (1) linearity of relations; (2) residual normality; (3) homoscedasticity (constant variance); and (4) independence (Vanhove, 2019). If the outcomes is not normally distributed, it may be transformed using several alternative methodologies, such as the logarithm or square-root transformation. As outliers may bias estimated parameters of the

model, observations whose standardized residual values are higher than 3, are generally excluded in the analysis. If the homogeneity of variance is not satisfied, then the heterogeneity can be taken into account by using a general least square estimation with a respective adaptation that allows for heteroscedasticity (GLS). This information is valuable in describing the association between a predictor like PA and a response variable like mental health problems while adjusting for other potential confounders.

### 2.3.2 Autoregressive Cross-lagged Model

The autoregressive cross-lagged model is an example of a structural equation model (SEM) that uses longitudinal data to analyze the ways in which the variables within the model are related to one another over the course of time (Selig & Little, 2012). This model is useful for determining the long-term impacts of psychopathologies and the associations between those conditions and the factors that cause and/or prevent them. The autoregressive effects of the variables upon themselves at an earlier point in time provide a description of the consistency of individual differences from one occurrence to the next. The cross-lagged effects provide a measurement of the impact that one construct has on another over the course of time (Selig & Little, 2012). In this cumulative dissertation, the main focus was on the cross-lagged effects between PA and mental health problems. The models are referred to as “crossed” due to the fact that they predict relationships between one variable and another, as well as vice versa. They are referred to as “lagged” models due to the fact that they evaluate the relationships between variables over a range of time points. Therefore, cross-lagged panel models allow to determine whether relationships across time are uni- or bi-directional (Kearney, 2017).

Usually several nested models are estimated and compared in order to ascertain which model provides the best fit to the data. The basic model incorporates both adjacent and distant autoregressive pathways; the subsequent model additionally includes cross-lagged pathways as well as covariates for the purpose of model comparison. When comparing nested models, fit indices, such as CFI, TLI, and RMSEA, as well as likelihood ratio tests, are utilized.

### 2.3.3 Latent Class Mixed Models

Latent class mixed models (LCMM) can be used to uncover distinct subpopulations within a population that differ with respect to an outcome or a trajectory of out. They also allow to incorporate correlated non-normally distributed outcomes and to classify individuals (McCulloch

et al., 2002). We used LCMM in order to identify unobserved subgroups of trajectories of general mental health problems, ADHD symptoms, and PA. Models with a different number of groups were compared to determine the best model for each variable. Parameter estimates for the different subgroups are based on maximum likelihood estimates, which are derived using a modified Marquardt algorithm with strict convergence requirements (Proust-Lima et al., 2017). Goodness-of-fit criteria, like the Bayesian information criterion (BIC), the Akaike information criterion (AIC), Entropy and class size were considered to select the model which described data the best.

### 2.3.4 Joint Trajectory Model

The relationship between developmental trajectories of several variables can be examined by joint trajectory models (Nagin & Tremblay, 2001). After identifying the distinct classes of developmental trajectories of general mental health problems, ADHD symptoms, and PA over three time points, we employed crosstabs analyzed their relationships. Through the use of this methodology, we were able to explore whether an individual's probability of having a specific trajectory of general mental health problems or ADHD symptoms is conditional on the latent trajectories of PA. This knowledge is valuable for understanding how the development of mental health disorders in boys and girls is associated with their PA trajectories, and whether PA might function as a preventative and/or treatment factor in children and adolescents.

## Chapter 3 – Original Manuscripts

This chapter contains two papers that have been published and one paper that is submitted to an international journal.

The *first study* used a multi-linear regression to explore the cross-sectional relationship between PA and mental health problems, including ADHD symptoms, while controlling for sex, SES, and BMI in three distinct age groups (preschool, elementary school and adolescents) at Baseline, Wave 1, and Wave 2, separately. The findings highlighted the significance of a high frequency level of PA in promoting mental health status in both children and adolescents.

Ganjeh, P., Meyer, T., Hagmayer, Y., Kuhnert, R., Ravens-Sieberer, U., Steinbuechel, N., Rothenberger, A., Becker, A. (2021). Physical activity improves mental health in children and adolescents irrespective of the diagnosis of attention-deficit/hyperactivity disorder (ADHD) - a multi-wave analysis using data from the KiGGS study. Int. J. Environ. Res. Public Health 18, 2207. doi: 10.3390/ijerph18052207

The *second study* revealed the longitudinal relationship between PA and general mental health problems, as well as symptoms of ADHD in children and adolescents, using different analyses for boys and girls. The findings showed that PA has long-term consequences on psychopathologies, particularly in preschool children.

Ganjeh, P., Hagmayer, Y., Meyer, T., Kuhnert, R., Ravens-Sieberer, U., von Steinbuechel, N., Rothenberger, A. and Becker, A. (2022). Physical activity and the development of general mental health problems or attention-deficit hyperactivity disorder (ADHD) symptoms in children and adolescents: A cross-lagged panel analysis of long-term follow-up epidemiological data. Front. Behav. Neurosci. 16:933139. doi: 10.3389/fnbeh.2022.933139

The *third study* examined children’s and adolescents' concurrent development of general mental health problems, ADHD, and PA over a ten-year period. The results showed (1) distinct

developmental trajectories for each component (for boys and girls separately) but, (2) a significant relationship between trajectories could not be found.

Ganjeh, P., Hagmayer, Y., Meyer, T., Kuhnert, R., Ravens-Sieberer, U., von Steinbuechel, N., Rothenberger, A., and Becker, A. (submitted). Physical activity and psychopathology: Are long-term developmental trajectories of physical activity in youngsters associated with trajectories of general mental health problems and of attention-deficit hyperactivity (ADHD) symptoms?

## 3.1 Original Article 1

Ganjeh, P., Meyer, T., Hagmayer, Y., Kuhnert, R., Ravens-Sieberer, U., Steinbuechel, N., Rothenberger, A., Becker, A. (2021). Physical activity improves mental health in children and adolescents irrespective of the diagnosis of attention-deficit/hyperactivity disorder (ADHD) - a multi-wave analysis using data from the KiGGS study. Int. J. Environ. Res. Public Health 18, 2207. doi: 10.3390/ijerph18052207

International Journal of
*Environmental Research and Public Health*

MDPI

*Article*

# Physical Activity Improves Mental Health in Children and Adolescents Irrespective of the Diagnosis of Attention Deficit Hyperactivity Disorder (ADHD)—A Multi-Wave Analysis Using Data from the KiGGS Study

**Parisa Ganjeh [1,*], Thomas Meyer [2,3], York Hagmayer [4], Ronny Kuhnert [5], Ulrike Ravens-Sieberer [6], Nicole von Steinbuechel [7], Aribert Rothenberger [1,†] and Andreas Becker [1,†]**

1 Department of Child and Adolescent Psychiatry and Psychotherapy, University Medical Center Göttingen, 37075 Göttingen, Germany; arothen@gwdg.de (A.R.); abecker4@gwdg.de (A.B.)
2 Department of Psychosomatic Medicine and Psychotherapy, University Medical Center Göttingen, 37073 Göttingen, Germany; thomas.meyer@med.uni-goettingen.de
3 German Centre for Cardiovascular Research (DZHK), Partner Site Göttingen, 37073 Göttingen, Germany
4 Department of Cognitive Science and Decision Psychology, Georg Elias Müller Institute of Psychology, University of Göttingen, 37073 Göttingen, Germany; york.hagmayer@bio.uni-goettingen.de
5 Department of Epidemiology and Health Monitoring, Robert Koch Institute, 13353 Berlin, Germany; kuhnertr@rki.de
6 Department of Child and Adolescent Psychiatry, Psychotherapy and Psychosomatics, University Medical Center Hamburg-Eppendorf, 20246 Hamburg, Germany; ravens-sieberer@uke.uni-hamburg.de
7 Institute of Medical Psychology and Medical Sociology, University Medical Center Göttingen, 37073 Göttingen, Germany; nvsteinbuechel@med.uni-goettingen.de
* Correspondence: parisa.ganjeh@med.uni-goettingen.de; Tel.: +49-0551-396-6947
† These authors are joint senior authors on this work.

**Abstract:** Physical activity (PA) may have positive effects on mental health in children and adolescents. This post hoc study aimed to further investigate the relationship between different frequency levels of PA and general mental health as well as specific hyperactivity/inattention symptoms in children and adolescents. Methods: The analyses were based on data drawn from the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) study, a regularly conducted large-scale, epidemiological investigation of somatic and mental health of children and adolescents in Germany. Parents were asked about their children's attention deficit hyperactivity disorder (ADHD) records and answered questionnaires concerning any mental health problem behavior of the children and adolescents using the Strengths and Difficulties Questionnaire (SDQ). The overall problem score as well as the hyperactivity/inattention symptoms subscale (SDQ-H/I) were entered as outcomes in a regression model controlling for parental socio-economic status and participants' sex, age, and body mass index (BMI). Cross-sectional analyses were conducted at three time points of the KiGGS study (baseline, wave 1, and wave 2) using general linear models (GLM). This was performed for different age groups (4–5, 6–9, 10–17 years). Results: Significant negative relationships were found between PA and general mental health problems. For the relationship between PA and SDQ-H/I, different patterns emerged at the three time points. There was no interaction between PA frequency levels and diagnosis of ADHD (ADHD vs. non-ADHD controls) regarding the SDQ total score. Conclusion: This study underlines the importance of a high frequency level of PA for a good mental health status among children and adolescents, irrespective of the diagnosis of ADHD.

**Keywords:** ADHD; adolescents; children; KiGGS; long-term effects; mental health; physical activity; Strengths and Difficulties Questionnaire



**Citation:** Ganjeh, P.; Meyer, T.; Hagmayer, Y.; Kuhnert, R.; Ravens-Sieberer, U.; von Steinbuechel, N.; Rothenberger, A.; Becker, A. Physical Activity Improves Mental Health in Children and Adolescents Irrespective of the Diagnosis of Attention Deficit Hyperactivity Disorder (ADHD)—A Multi-Wave Analysis Using Data from the KiGGS Study. *Int. J. Environ. Res. Public Health* **2021**, *18*, 2207. https://doi.org/10.3390/ijerph18052207

Academic Editors: Cheng-Fang Yen, Liang-Jen Wang, Ray C. Hsiao, Mu-Hong Chen and Yi-Ling Chien

Received: 29 January 2021
Accepted: 17 February 2021
Published: 24 February 2021

## 1. Introduction

For adults, it is already known that, in general, physical activity (PA) is effective for the prevention and treatment of somatic diseases including heart diseases, cancers, diabetes mellitus, stroke, and overweight [1,2]. In contrast, physical inactivity may have negative consequences for individuals, family, and the community, directly and indirectly increasing costs to the healthcare system [1]. Several reports have shown that PA not only improves physical health but also may have a positive impact on mental health problems, well-being, and quality of life [3–9]. Although the number of studies investigating PA and mental illness in adults is increasing [10–17], results pertaining to this relationship in children and adolescents are mixed and even scarce. Hence, more studies are needed in order to obtain a clearer picture before firm conclusions can be drawn, specifically those addressing PA for prevention and treatment of developmental psychopathology, either in general or for a specific disorder. In non-adult populations, PA may lead to improvement of emotional mental health and social support, and also may raise self-esteem [18–22].

There are several empirical studies suggesting positive effects of PA on mental health among children and adolescents [23–32], however, contradictory results have also been published [33,34]. In a cross-sectional study, O'Brien et al. investigated the relationship between PA and the risk of psychological problems among early school-aged children and found no significant association [35]. Other studies, conducted among young children, found limited evidence for an inverse negative correlation between sports or PA and emotional symptoms/conduct problems, hyperactivity/inattention, and behavioral problems [36,37]. In their review and meta-analysis of the effect of PA interventions on mental health outcomes in preschoolers (2–5 years of age), elementary-school children (6–11 years of age), and adolescents (12–18 years of age), Rodriguez-Ayllon et al., demonstrated a small but significantly beneficial effect of PA on mental health in 6- to 18-year-old children and adolescents (Cohen's d = 0.173) [38]. However, when they performed separate analyses for children and adolescents, the results were significant for the latter but not for the former. Moreover, it is not clear whether PA is more relevant for general or rather only for certain specific psychopathologies. Therefore, further research on different age groups and mental health problems seems to be essential before firm conclusions for practical interventions may be drawn.

With regard to psychopathological specificity and clear relatedness of motoric restlessness to PA, we referred to one of the most common and practically important externalizing psychiatric disorders in childhood and adolescence, namely, attention deficit hyperactivity disorder (ADHD), which is characterized by age-inappropriate degrees of inattention, impulsivity, and hyperactivity, frequently leading to long-term academic, social, and mental health problems [39,40]. The usual first line treatment for ADHD differs depending on age. For preschool children, behavior therapy is the most commonly recommended treatment. For elementary school children and adolescents, medications are the major line of treatment [41]. However, there can be negative side effects of psychopharmacological treatment [42,43]. Moreover, about one-third of children may not experience a sufficient reduction in ADHD symptoms after stimulant medication and behavioral treatment [44]. Possibly, PA might play a prominent role as an alternative and/or supplementary treatment and protective factor for children with ADHD [45].

A number of studies, reviews, and meta-analyses have already documented some benefits of PA for ADHD-diagnosed children, including reductions in ADHD symptoms, improved academic achievement, as well as socio-emotional and cognitive performance [46–59]. For example, an intervention study reported major reduction in ADHD symptoms among children during PA sessions, observed by teachers in school. Moreover, these teachers reported a general increase in involvement in the classroom educational activities [57]. A recent meta-analysis provides evidence that physical exercise may lead to a significant reduction in anxiety and depression symptoms, aggressive behavior, and social problems in ADHD children [58].

When studying health behaviors and ADHD in children aged 11 to 17 years van Egmond-Fröhlich and colleagues observed a weak but significant positive relationship between the child's self-report of medium-high intensity PA and the parent-rated hyperactivity/inattention score [60]. In addition, several meta-analyses reported that the positive results of many studies have to be interpreted with caution because of various factors, including low effect sizes, large differences in study designs and group compositions (specifically, no comparison of different age groups), small sample sizes, small number of studies, no randomization or blinding method, lack of sufficient control conditions, no healthy control group, risk of bias, and the heterogeneity of their outcome measures [45,48,61]. In addition, the present evidence is insufficient to provide a clear positive statement for different age groups during childhood and adolescence and recommendation for PA as part of a treatment program in children and adolescents with mental health problems [45,48,52,58,61].

The present study addressed some of the limitations of previous work and aimed to broaden and deepen the existing knowledge. To this end, we used epidemiological behavioral data (including PA) of a large sample size with different age groups of children and adolescents at three different time points and measured child and adolescent mental health problem behavior in general and specific aspects in order to test whether PA may have a differentiating effect. Studying groups of children at different periods of their development can provide us with more reliable results about the effect of PA on mental health in children and adolescents. Hence, if the same results were repeated at different time points, we could infer that the effect of PA on mental health of children and adolescents works irrespective of the time period and the kind of psychopathology in question, supporting the reliability of the observed results.

The aims of this study were threefold: (1) to examine the relationship between PA and general mental health problems in different age groups in children and adolescents, (2) to investigate the association between PA and ADHD symptoms during development from childhood to early adulthood, and (3) to assess the role of ADHD diagnosis (ADHD as compared to non-ADHD controls) as a possible moderator of the association between different levels of PA and mental health problems in a wide age range of German children and adolescents.

## 2. Materials and Methods

### *2.1. Participants and Procedures*

Since 2003, the Robert Koch Institute (RKI) has followed the health of children and adolescents in Germany, investigating representative samples of children into late adolescence/young adulthood in the regularly conducted cross-sectional part of the German Health Interview and Examination Survey for children and adolescents (KiGGS). Aims, background, and design of the KiGGS study are described in detail elsewhere [62–64]. In brief, 17,640 girls and boys aged from aged from 0 to 17 years and their parents participated in the KiGGS baseline survey from 2003 to 2006. Participants were randomly selected at 167 study sites using a stratified sampling method. The response rate was 66.6%. Six years later, KiGGS wave 1 (2009–2012) was conducted via telephone interviews. The sample of KiGGS wave 1 consisted of a new cross-sectional sample of 0- to 6-year-old children randomly drawn from the population registers of the original 167 study sites. In addition, the earlier participants of the KiGGS baseline survey were again invited to the survey, who were then 6 to 24 years old and continued as a closed cohort. Overall, 12,368 children and adolescents (6093 girls, 6275 boys) participated, with an age range from 0 to 17 years, including 4455 first-timers (response rate 38.8%) and 7913 re-invited participants (response rate 72.9%) [65]. Overall, 15,023 children and adolescents aged from 0 to 17 years participated in KiGGS wave 2 (2014–2017), which included a physical examination. There were 10,853 girls and boys from the baseline group who were part of the longitudinal sample of the second wave (with a response rate of 61.5%) [66].

### 2.2. Selection of Groups

Three different age groups were selected (preschool children, elementary school children, and adolescents) on the basis of different psychosocial developmental aspects and the challenges that these age groups face. By keeping the same participants over a time course of about 10 years, analysis of these longitudinal data gives us a chance to compare the results between the separate waves with no need to pair the participants or to control the disturbing variables. In a first step, the longitudinal data for the age range from 4 to 17 years were used to run cross-sectional analyses at the three measurement points. Hence, we had to leave out the data of children older than 17 years at a certain measurement point. Therefore, we could analyze data of three age groups at baseline (4–5, 6–9, 10–17 years), two age groups at wave 1 (6–9, 10–17 years), and only one group at wave 2 (10–17 years). Because ADHD can be validly diagnosed only from the age of 4, our sample selection was taken from that age.

### 2.3. Measurements

Physical activity: Data for PA were obtained from parents' answers to one question given at baseline ("In how much sport and physical activity does your child take part?"). There were three response categories, namely 1 = low, 2 = medium, and 3 = high. Physical activity was measured through a parent-reported question according to WHO recommendation for children and adolescents at waves 1 and 2. The question was "On how many days is your child at least 60 min physically active during a normal week?". The response range was from 0 = never to 7 = 7 days a week. The response range of the question at waves 1 and 2 was categorized according to the baseline in order to have a better comparison between time points (never to 2 days per week = low, 3 to 5 days per week = medium, and 6 to 7 days per week = high). PA was used as a categorical variable with three frequency levels (low, medium, and high) in this study.

Mental health problems and ADHD symptoms: In the KiGGS study, mental health was evaluated by parent- and self-report using the Strengths and Difficulties Questionnaire (SDQ) [67]. The SDQ includes 25 items with statements that are rated from 0 = not true to 2 = certainly true. The SDQ has five subscales, namely emotional problems, conduct problems, hyperactivity/inattention, peer problems, and prosocial behavior. The score of each subscale ranges between 0 and 10. The total difficulties score is obtained as the sum of the four subscales (including all, except for prosocial behavior) and ranges between 0 and 40. A higher score indicates more difficulties. In the current study, the parent-report of total difficulties and the hyperactivity/inattention subscale (SDQ-H/I) were used as indicator for general mental health problems and symptoms of ADHD, respectively. Psychometric properties of the questionnaire were investigated in normal [68] and clinical [69] samples of German children and adolescents. The scores are reliable and highly correlated with the Child Behavior Checklist (CBCL). The questionnaire is valid to distinguish psychiatric patients and different categories of disorders in the clinical sample [68,69]. In the present study, Cronbach's alphas for total score of SDQ and SDQ-H/I subscale were 0.80 and 0.76, respectively.

In the KiGGS study, parents were asked "Has your child ever been diagnosed with an attention deficit/hyperactivity disorder by physicians or psychologists?". This item was used for grouping children and adolescents as diagnosed with ADHD versus a control group without diagnosis. Parental socio-economic status [70] and participants' sex, age, and body mass index (BMI) were used as covariates in the analyses. The correlation between covariates and dependent variables was estimated at each age category, and if there was a significant correlation among them, the covariate was used in the analysis.

### 2.4. Analyses

This cross-sectional, post hoc analysis was conducted at each time point separately according to available data for PA, SDQ, and the diagnosis of ADHD. Three kinds of analyses were run: (1) comparison of the SDQ score between frequency levels of PA, (2)

comparison of the SDQ-H/I score between frequency levels of PA, and (3) interactions between PA and diagnosis of ADHD (ADHD vs. control) taking the SDQ score into account. Predictors were categorical (three levels of PA in the association and interaction analyses and two groups of ADHD diagnosis in the interaction analysis) and outcomes were continuous (total SDQ and SDQ-H/I scores). Therefore, a general linear model (GLM) was used to analyze the data. Before running the analyses, we checked assumptions of GLM (homoscedasticity and normal distribution). If the assumptions were not met, outcomes were transformed by using the square-root method. Moreover, the normality of the distribution of the residual was tested. These checks had an effect on the making of the decision to transform the data. If the standardized values of residuals were larger than ±3, the data points were removed from the analysis (the deleted data were fewer than 1%). If, after transforming, the homogeneity of variance was still not met, a general least square model (GLS) taking the heterogeneity into account was used. After fitting a model, differences in outcomes between the three frequency levels of PA were analyzed by between-group contrasts. A negative estimate means that the total SDQ score or SDQ-H/I score was higher at a lower level of PA. To analyze for an interaction between frequency levels of PA and the parent-reported diagnosis of ADHD (ADHD vs. controls) with respect to the total SDQ score, we compared a model including the interaction term to a model not including the interaction term. Because there was a large difference between the number of children diagnosed with ADHD and controls, a propensity score matching was used in order to obtain a reliable result in the interaction analysis. Matching for ADHD diagnosis groups was conducted according to a PA variable. All analyses were conducted using R including the packages haven, car, MatchIt, psych, and nlme [71], and IBM SPSS Statistics for Windows, Version 26.0 (International Business Machines Corporation, New York, NY, USA).

## 3. Results

### 3.1. Descriptive Statistics

According to a meta-analysis that found different results for children and adolescents in separate analyses [38], we chose different age groups in order to better compare the results. The total numbers of children and adolescents at baseline, wave 1, and wave 2 were 13,901, 8501, and 4598, respectively. The descriptive statistics regarding the analysis of the different age groups for each of the three time points is reported in Tables 1–3.

**Table 1.** Descriptive characteristics of the study population at baseline.

| Variables/Age Group | 4–5 Years (4.49 ± 0.05) | | 6–9 Years (7.52 ± 1.11) | | 10–17 Years (13.37 ± 2.26) | |
|---|---|---|---|---|---|---|
| | *N* | Mean ± SD | *N* | Mean ± SD | *N* | Mean ± SD |
| Participants | 1935 | | 4136 | | 7830 | |
| SDQ | | | | | | |
| Total difficulties | 1904 | 8.31 ± 4.49 | 4059 | 8.43 ± 5.25 | 7564 † | 8.18 ± 5.26 |
| Hyperactivity/inattention | 1906 | 3.40 ± 2.20 | 4062 | 3.34 ± 2.36 | 7571 † | 2.7 ± 2.8 |
| PA | 1829 | | 3867 | | 7614 | |
| Low | 566 (30.9%) | | 819 (21.2%) | | 3208 (42.1%) | |
| Medium | 702 (36.3%) | | 1377 (35.6%) | | 2385 (31.3%) | |
| High | 561 (30.7%) | | 1671 (43.2%) | | 2021 (26.5%) | |
| ADHD | 58 | | 332 | | 860 | |
| Diagnosed | 29 (50%) | | 166 (50%) | | 430 (50%) | |
| Control | 29 (50%) | | 166 (50%) | | 430 (50%) | |
| **Descriptive characteristics were used in the model after control of covariates** | | | | | | |
| | **SDQ-total *N* (Mean)** | **SDQ-H/I *N* (Mean)** | **SDQ-total *N* (Mean)** | **SDQ-H/I *N* (Mean)** | **SDQ-total *N* (Mean)** | **SDQ-H/I *N* (Mean)** |
| PA | | | | | | |
| Low | 548 (9.38 ± 4.86) | 549 (3.79 ± 2.31) | 791 (9.90 ± 5.60) | 797 (3.78 ± 2.37) | 3040 (8.38 ± 5.2) | 3045 (2.73 ± 2.11) |
| Medium | 695 (8.18 ± 4.4) | 695 (3.37 ± 2.17) | 1362 (8.69 ± 5.32) | 1366 (3.40 ± 2.40) | 2287 (7.52 ± 4.96) | 2284 (2.69 ± 2.10) |
| High | 533 (7.41 ± 4.04) | 553 (3.02 ± 2.09) | 1648 (7.42 ± 4.77) | 1652 (3.05 ± 2.26) | 1932 (8.16 ± 5.17) | 1936 (3.13 ± 2.22) |
| Total | 1796 (8.31 ± 4.51) | 1797 (3.39 ± 2.21) | 3801 (8.39 ± 5.24) | 3815 (3.33 ± 2.35) | 7259 (8.05 ± 5.14) | 7265 (2.83 ± 2.15) |

† Numbers after deleting outliers.

**Table 2.** Descriptive characteristics of the study population at wave 1.

| Variables<br>Age Group | 6–9 Years (7.55 ± 1.10) | | 10–17 Years (13.53 ± 2.26) | |
|---|---|---|---|---|
| | *N* | Mean ± SD | *N* | Mean ± SD |
| Participants | 2548 | | 5953 | |
| SDQ | | | | |
| Total difficulties | 2534 † | 8.53 ± 4.92 | 5865 † | 7.90 ± 4.87 |
| Hyperactivity/ inattention | 2546 | 3.29 ± 2.25 | 5861 † | 2.75 ± 2.08 |
| PA | 2535 | | 5615 | |
| Low | 305 (12%) | | 1389 (24.7%) | |
| Medium | 1120 (44.2%) | | 2985 (53.2%) | |
| High | 1110 (43.8%) | | 1241 (22.1%) | |
| ADHD | 158 | | 646 | |
| Diagnosed | 79 (50%) | | 323 (50%) | |
| Control | 79 (50%) | | 323 (50%) | |
| **Descriptive characteristics were used in the model after control of covariates** | | | | |
| | **SDQ-total**<br>***N* (Mean)** | **SDQ-H/I**<br>***N* (Mean)** | **SDQ-total**<br>***N* (Mean)** | **SDQ-H/I**<br>***N* (Mean)** |
| PA | | | | |
| Low | 202<br>(9.74 ± 5.21) | 203<br>(3.62 ± 2.23) | 1145<br>(8.65 ± 4.95) | 1369<br>(2.72 ± 2.07) |
| Medium | 818<br>(8.58 ± 4.81) | 824<br>(3.32 ± 2.24) | 2452<br>(7.50 ± 4.60) | 2926<br>(2.61 ± 2.01) |
| High | 708<br>(8.25 ± 5.02) | 713<br>(3.20 ± 2.28) | 1031<br>(7.93 ± 5.09) | 1224<br>(3.06 ± 2.20) |
| Total | 1728<br>(8.58 ± 4.97) | 1740<br>(3.31 ± 2.26) | 4628<br>(7.88 ± 4.82) | 5519<br>(2.74 ± 2.07) |

† Numbers after deleting outliers.

**Table 3.** Descriptive characteristics of the study population at wave 2.

| Variables/Age Group | 10–17 Years (14 ± 1.99) | |
|---|---|---|
| | *N* | Mean ± SD |
| Participants | 4598 | |
| SDQ | | |
| Total difficulties | 4502 | 7.13 ± 4.89 |
| Hyperactivity/inattention | 4472 † | 2.51 ± 1.97 |
| PA | 4367 | |
| Low | 1214 (27.8%) | |
| Medium | 2173 (49.8%) | |
| High | 980 (22.4%) | |
| ADHD | 494 | |
| Diagnosed | 247 (50%) | |
| Non-diagnosed | 247 (50%) | |
| **Descriptive characteristics were used in the model after control of covariates** | | |
| | **SDQ-total**<br>***N* (Mean)** | **SDQ-H/I**<br>***N* (Mean)** |
| PA | | |
| Low | 936 (7.84 ± 5.04) | 1185 (2.47 ± 1.95) |
| Medium | 1737 (6.59 ± 4.62) | 2119 (2.35 ± 1.92) |
| High | 768 (7.26 ± 5.19) | 953 (2.78 ± 2.06) |
| Total | 3441 (7.08 ± 4.89) | 4257 (2.48 ± 1.97) |

† Numbers after deleting outliers.

Ultimately the SDQ total score had to be transformed using the square-root technique (SQRT), whereas the SDQ-H/I score did not have to be transformed. Only the SDQ-H/I score in the 6- to 9-year-old age group at wave 1 was transformed by employing the square-root technique (SQRT). GLS was also used for the interaction model among 6- to 9-year-old children at baseline.

All models were compared with their null model to evaluate whether they were parsimonious and significant. The F estimators were significant for the main models ($p$-values $\geq$0.001 and $\leq$0.05).

### 3.2. Results at Baseline

Next, we tested whether there was an inverse relationship between PA levels and the total SDQ score. At baseline (Table 4), the result showed that indeed there was a difference between the levels of PA with regard to the total SDQ scores. Children with a high level of PA had less general mental health difficulties than children with a medium level of PA (Es = −0.11, t = −2.64, $p$ = 0.01, Beta = 0.14) and a low level of PA (Es = −0.20, t = −4.26, $p$ = 0.001, Beta = 0.25) among 4- and 5-year-old children. There was no significant difference between medium and low level of PA in this age range.

**Table 4.** Results at baseline, wave 1, and wave 2 showing associations of physical activity (PA), mental health problem (Strengths and Difficulties Questionnaire [SDQ] total), and ADHD symptoms (SDQ hyperactivity/inattention subscale (SDQ-H/I)).

| | Age Groups | PA | SDQ-Total | | | SDQ-H/I | | |
|---|---|---|---|---|---|---|---|---|
| | | | Estimate (SE) | T Value | Coefficient (std.) | Estimate (SE) | T Value | Coefficient (std.) |
| Baseline | 4–5 years | Low-medium | −0.09 (0.05) | −1.944 | −0.11 | −0.12 (0.12) | −1.01 | −0.06 |
| | | Low-high | −0.20 (0.05) | −4.26 *** | −0.25 | −0.41 (0.13) | −3.13 ** | −0.19 |
| | | Medium-high | −0.11 (0.04) | −2.64 ** | −0.14 | −0.28 (0.12) | −2.37 * | −0.13 |
| | 6–9 years | Low-medium | −0.106(0.04) | −2.60 ** | −0.11 | −0.13 (0.10) | −1.31 | −0.06 |
| | | Low-high | −0.33 (0.04) | −8.28 *** | −0.35 | −0.48 (0.09) | −4.84 *** | −0.21 |
| | | Medium-high | −0.23 (0.03) | −6.85 *** | −0.24 | −0.35 (0.08) | −4.25 *** | −0.15 |
| | 10–17 years | Low-medium | −0.21 (0.02) | −8.75 *** | −0.24 | −0.26 (0.05) | −4.56 *** | −0.12 |
| | | Low-high | −0.16 (0.02) | −6.11 *** | −0.18 | −0.02 (0.06) | −0.30 | −0.01 |
| | | Medium-high | 0.05 (0.02) | 1.97 * | 0.06 | 0.24 (0.06) | 3.85 *** | 0.11 |
| Wave 1 | 6–9 years | Low-medium | −0.11 (0.06) | −1.79 | −0.14 | −0.04 (0.05) | −0.69 | −0.05 |
| | | Low-high | −0.21 (0.06) | −3.24 ** | −0.25 | −0.12 (0.06) | −2.08 * | −0.16 |
| | | Medium-high | −0.09 (0.04) | −2.28 * | −0.11 | −0.08 (0.03) | −2.18 * | −0.11 |
| | 10–17 years | Low-medium | −0.22 (0.03) | −7.18 *** | −0.25 | −0.21 (0.06) | −3.27 ** | −0.10 |
| | | Low-high | −0.21 (0.03) | −5.58 *** | −0.24 | 0.04 (0.08) | 0.59 | 0.02 |
| | | Medium-high | 0.01 (0.03) | 0.40 | 0.01 | 0.26 (0.06) | 3.86 *** | 0.13 |
| Wave 2 | 10–17 years | Low-medium | −0.26 (0.03) | −6.88 *** | −0.27 | −0.23 (0.06) | −3.46 *** | −0.12 |
| | | Low-high | −0.20 (0.04) | −4.40 *** | −0.21 | −0.01 (0.08) | −0.16 | −0.01 |
| | | Medium-high | 0.057 (0.04) | 1.40 | 0.06 | 0.22 (0.07) | 3.05 ** | 0.11 |

* Significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level, coefficient (std) = Beta, PA: physical activity, SDQ-total: total Strengths and Difficulties Questionnaire score, SDQ–H/I: symptoms of ADHD measured using the score of the hyperactivity/inattention subscale of SDQ.

Among children between 6 and 9 years of age, a higher PA level was significantly associated with lower scores of total difficulties (Table 4). In all of these comparisons, the effect sizes were small to medium [72]. Only in study participants aged 6–9 years, there was a large effect size for the difference between high- and low-level activity (Es = −0.33, t = −8.28, $p$ = 0.001, Beta = 0.35).

Compared to children with a low level of PA, the mean score of total difficulties at baseline was lower in children of 10–17 years of age with a high level of PA (Es = −0.16, t = −6.11, $p$ = 0.001, Beta = 0.18) and children with a medium level of PA (Es = −0.21, t = −8.75, $p$ = 0.001, Beta = 0.24) (Table 4). In this age group, there was an unexpected result for the comparison between a medium and high level of PA (Table 4). The 10- to 17-year-old children with a high level of PA had significantly greater difficulties than children with a medium level of PA (Es = 0.05, t = 1.97, $p$ = 0.05, Beta = 0.06).

The results for the second aim (negative association between SDQ-H/I symptoms and level of PA) at baseline are also reported in Table 4. Among preschool children (aged 4 and 5 years), a high level of PA was linked to a reduced SDQ-H/I score in comparison to a low level (Es = −0.41, t = −3.13, $p$ = 0.01, Beta = 0.19) and a medium level of PA (Es = −0.28, t = −2.37, $p$ = 0.05, Beta = 0.13), while no significant difference between low and medium levels of PA was observed. These results were similar among 6- to 9-year-old children (Table 4).

Among adolescents aged 10–17 years, the mean score of ADHD symptoms was lower at a medium level of PA than at a low level of PA (Es = −0.26, t = −4.56, $p$ = 0.001, Beta = 0.12). Similar to the result for total difficulties, children with a high level of PA showed more symptoms of ADHD in comparison to children with a medium level (Es = 0.24, t = 3.85, $p$ = 0.001, Beta = 0.11).

An objective of this study was to investigate the role of receiving an ADHD diagnosis in the relationship between PA and total difficulties. The interaction between levels of PA and diagnosis of ADHD (ADHD vs. controls) was not significant across all age groups. The results from the groups aged 6–9 and 10–17 years were $\chi^2(2) = 1.10$, $p$ = 0.57, and $\chi^2(2) = 3.20$, $p$ = 0.20, respectively. At the age group of 4–5 years, the sample size was not large enough to analyze the interaction between PA and both groups.

### 3.3. Results at Wave 1

The results for participants at wave 1 are reported in Table 4. Among children aged 6–9 years, the mean of total SDQ score was significantly lower at a high level of PA than at a low (Es = −0.21, t = −3.24, $p$ = 0.01, Beta = 0.25) or medium level of PA (Es = −0.09, t = −2.28, $p$ = 0.05, Beta = 0.11). There was no difference between low and medium levels in this age range. Adolescents aged 10–17 years showed a significant inverse and medium difference between a high and a medium level of PA in comparison to a low level of PA. However, the difference between a high and a medium level of PA was non-significant.

Although the mean score of SDQ-H/I was lower at a higher level of PA, the difference was only significant between a low and a high level of PA (Es = −0.12, t = −2.08, $p$ = 0.05) with a small effect size (Beta = 0.16) and a medium and a high level of PA (Es = −0.08, t = −2.18, $p$ = 0.05, Beta = 0.11) among 6–9-year-old children (Table 4). In the age group of 10–17 years, hyperactivity/inattention symptoms were lower for a medium level of PA than for a low level of PA (Es = −0.21, t = −3.27, $p$ = 0.01, Beta = 0.10). The difference was not significant between a low and a high level. Adolescents aged 10–17 years showed more ADHD symptoms at a high level of PA in comparison to a medium level (Es = 0.26, t = 3.86, $p$ = 0.001, Beta = 0.13).

In the children and adolescents aged between 10 and 17 years, there was no significant interaction ($\chi^2(2) = 0.50$, $p$ = 0.77) between frequency levels of PA and the two groups of subjects with ADHD diagnosis and controls. At 6–9 years of age, the sample size was not large enough to conduct an interaction analysis.

### 3.4. Results at Wave 2

At wave 2, data were only available for adolescents aged 10–17 years (Table 4). The results showed that the mean total SDQ score at a low level of PA was higher than at a medium (Es = −0.26, t = −6.88, $p$ = 0.001, Beta = 0.27) and a high level (Es = −0.20, t = −4.40, $p$ = 0.001, Beta = 0.21).

Adolescents who were active at a medium level showed fewer ADHD symptoms (Es = −0.23, t = −3.46, $p$ = 0.001, Beta = 0.12) than those with a low activity, but there was no significant difference between a low and a high level of PA with respect to SDQ-H/I score. The results in Table 4 show that adolescents and young adults with a high level of PA had more ADHD symptoms than those who were at a medium level of PA (Es = −0.22, t = 3.05, $p$ = 0.01, Beta = 0.11), albeit the effect size was very small. The interaction was not significant at this time point ($\chi^2$ (2) = 1.77, $p$ = 0.41).

## 4. Discussion

Since there is mixed empirical evidence with respect to the effect of PA on mental health in children and adolescents, this study aimed to further investigate this issue, expecting a negative relationship. General and specific (here ADHD as movement-related problem) developmental psychopathologies were chosen as probable differentiating factors.

The main finding of this large-scale, nationwide, epidemiologic, multi-cross-sectional study conducted in German children and adolescents of different developmental age

groups at three different time points demonstrated that higher physical activity was associated with better general mental health and lower specific symptoms of hyperactivity and inattention. In addition, no interaction was observed between PA and the two ADHD diagnosis groups (ADHD vs. non-ADHD controls) regarding general psychopathological difficulties in children and adolescents. From these data, it can be concluded that the relationship between PA and mental health problems is not influenced by the diagnosis of ADHD; i.e., inverse relationships between PA and mental health problems were found similarly in subjects both with ADHD diagnosis and control children.

### 4.1. Physical Activity and General Developmental Psychopathology

Results from this study suggest that children and adolescents who were more physically active showed better general mental health and thus fewer mental health problems, assuming that a high level of PA may be a protective factor against psychological problems in children and adolescents. The results were similar in all tested age groups at baseline, wave 1, and wave 2, respectively; the effect size was between low (low-high comparison in the age group of 4–5 years at baseline, Beta = 0.11) and medium (low-medium comparison in the 10–17 age group at wave 2, Beta = 0.27). These findings from the KiGGS study are consistent with previous work indicating a positive relationship between PA and mental health. In their systematic review, Dale et al. concluded that PA may lead to positive mental health among 5- to 17-year-old children and adolescents [19]. In the study by Vella et al., sport participation was a significant predictor of mental health trajectories in young children between the age of 4 and 12 years. In fact, children who did not participate in sport were 2.1 (odds ratio, OR) times more likely to be part of the high difficulty trajectory, representing the highest risk of mental health problems, than those who participated in sport [23]. Anxiety and depression symptoms were higher (OR 1.43 and 1.88, i.e., moderate to severe compared to no symptoms) among 14- and 15-year-old, physically inactive children [18]. Internalizing (hazard ratio [HR] = 0.81) and externalizing (HR = 0.65 and HR = 0.71 for 1–3 times and $\geq$4 times per week, respectively) disorders had lower occurrence among 10- and 11-year-old children who were physically active three times or more a week compared with those who were never physically active [24]. The results of the current study are compatible with the conclusion of a systematic review and meta-analysis conducted by Rodriguez-Ayllon et al., who found that PA leaves a significant positive influence on mental health in children and adolescents [38].

Generally, in the present study, a low level of PA was related to a higher score of mental problems. The findings among preschool children aged 4–5 years and 6–9 year-old elementary-school children at baseline and wave 1 were not congruent with data from the above-mentioned meta-analysis by Rodriguez-Ayllon and colleagues. The authors did not find a positive relationship between PA and mental health in younger children [38]. This difference might refer to the diverse methodology and (mostly small) sample sizes reported in the papers they included in their study. Likewise, O'Brien et al. reported no significant relationship between PA and mental health disorders in early school-aged Australian children [35]. The sample size in our study was quite large, and the positive relationship between PA and mental health was found at two time points in 6- to 9-year-old children. The effect sizes for the comparisons between low and high levels of PA were moderate to high (Beta = 0.25 to 0.35) in children aged 4–5 and 6–9 years at baseline and wave 1, but the effect sizes with respect to other comparisons between frequency levels of PA were quite low. These findings may imply that only at high levels can PA provide a buffer against mental problems in preschool and elementary school children.

Interestingly, in 10- to 17-year-old children at all three time points, adolescents with a high level of PA had more mental problems than those with a medium level of PA. However, this result was only weakly significant at baseline. Even though it opposes most of the previous works [18,24,38], this finding is highly consistent with results from a study by Hartman and co-workers [37]. These authors demonstrated that children, who were more physically active showed a somewhat higher risk of behavioral problems (SDQ measure),

although their study was conducted among younger children. The result might be, at least partly, explained by the fact that some adolescents take part more often in activities and sports that are more risky and not always recreational. Moreover, parents' expectations considering specific kinds of activities as useful and appropriate for their youngsters might have played a role. In the present study, the type of PA was not indicated.

### 4.2. Physical Activity and ADHD Symptoms

Our results showed that symptoms of ADHD were associated with a low level of PA. At baseline, parents reported significantly fewer symptoms of hyperactivity/inattention for children who were at the medium or high levels of PA compared to those who were at a low level. The gradual decrease in the SDQ-H/I score from the low to the high PA class suggests that PA may be considered as a health-related behavioral factor for ADHD symptoms at medium and high levels of PA, although the effect sizes were low to medium (0.13 to 0.21). These findings were consistent with several types of research that showed benefits of PA in children with ADHD [47,48,59]. Since the difference between levels of PA was not significant through age groups, it might be concluded that there is a specific range of PA that may serve as a protective element against hyperactivity/inattention symptoms.

Among preschool (4–5 years of age) and elementary-school children (6–9 years) at baseline and wave 1, the high level of PA was significantly associated with fewer reported symptoms of ADHD. However, the effect sizes were again small. Children who were at the medium level of PA had fewer symptoms of ADHD in comparison to low-level active children, but this association was not significant among 4 to 5- and 6 to 9-year-old children, respectively. This finding is inconsistent with previous research that reported that more PA was associated with more hyperactivity/inattention symptoms [36,37]. This disagreement may originate from the different methods for measuring PA. Kostyrka-Allchorne et al. used a parent-rated questionnaire (e.g., swimming, football, dancing) [36], whereas Hartman et al. used accelerometry (ActiGraph GT3X), which has some limitations for separating ADHD-related hyper-motoric behaviors from other physical activities [37].

Our data demonstrated that in children between 10 and 17 years, the score of ADHD symptoms was significantly higher at high level of PA as compared to the medium level at all three time points. The level of PA among adolescents may be a key factor in determining mental health and ADHD symptoms by the parents. It should be considered that effect sizes for these results were small, although they were statistically significant.

The findings of this part of the study showed that there is no similar and repetitive pattern for the association between PA and SDQ-H/I. In addition, associations were generally weak and a firm conclusion cannot be drawn regarding the effect of PA on ADHD symptoms.

### 4.3. Physical Activity and Dose-Response Effects

As already mentioned above, children with a low level of PA had more mental problems than those who presented with a medium or high level. These results were significant and constant in most comparisons at the three measurement points over time. It seems that the intensity and frequency of PA are two important factors in order to produce a positive effect on mental health. Moreover, other studies have reported that a higher level of PA is associated with better mental health [1,3,8,24,25,46–48]. For example, children who were physically active 1–3 or $\geq$4 times per week had a lower rate of internalizing and externalizing disorders in comparison to those who were never active [24]. McMahon et al. grouped PA into four categories from least active (0–3 days) to sufficiently active (14 days) within two weeks and found that a higher frequency of PA was associated with better well-being and lower levels of anxiety and depression in adolescents [25]. In another study it has been reported that the more frequent and intense exercise was associated with better self-regulation, emotional ability, and decreased hyperactivity and impulsivity in children [8]. Gallego-Méndez et al. reported that as the frequency of PA increased, ADHD children showed better scores in health-related quality of life [3]. In a systematic review of

exercise intervention in children and adolescents with ADHD, it was demonstrated that at least parents or teachers reported considerable positive effects of exercise on ADHD in studies evaluating the long-term effects of exercise [46]. Hence, it may be concluded that higher levels of PA might be associated with better mental health.

It should be considered that the range of effect sizes regarding the association between the frequency level of PA and its positive effect on mental health was always low to moderate. This holds not only for the current study but also for the several systematic reviews and meta-analyses that reported either weak effects or methodological shortcomings in this relationship [38,48,52]. Nevertheless, PA might be a supplementary protective factor for mental health.

This study has several strengths, which could overcome some weaknesses of earlier studies on the issue. The sample size was large and adequate for complex statistical analyses at the three sequential time points. Furthermore, three different developmental age groups could be separately tested at the three time points, representing roughly independent samples, but showing similar results for general and specific psychopathology (here: ADHD) at these three time points. Hence, this study presents reliable results, clarifying some of the uncertainties of research carried out thus far. However, this study also faced some limitations, for example, using only parents' reports for detecting psychopathology, transforming data in some of the models, using a one-item question for evaluating PA, and not specifying the type of PA. In addition, our findings are not representative of the German population due to oversampling of study participants from eastern parts of Germany, and no weighting factor was included in our analyses. Further research on PA and mental health problems should keep equally large sample sizes, like ours, and a developmental perspective (if possible in a longitudinal design). Moreover, multi-informant questionnaires for child behavior and PA, combined with actigraphy, could improve the demanded replication and extension of this practically important area of research.

## 5. Conclusions

The present post hoc study suggests that a medium and/or high level of PA is associated with both good general mental health and low ADHD symptoms in children and adolescents from the community. Thus, PA did not differentiate between its effects on general versus specific aspects of psychopathology. These findings support the WHO recommendation on the importance of regular PA among children and adolescents [73]. However, since our findings are associative, they should not be interpreted in a causal way. Only longitudinal investigations of the topic may be able to decide whether unfavorable general mental health may be an obstacle for a systematic application of PA, or whether PA may be considered as a supplementary factor in preventing and treating the psychopathology of children and adolescents.

**Author Contributions:** Conceptualization, P.G.; formal analysis, P.G.; methodology, P.G., Y.H.; writing—original draft, P.G.; writing—review and editing, P.G., A.R., Y.H., T.M., N.v.S., U.R.-S., R.K., A.B.; supervision, A.R. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Robert Koch Institute studies' data protection and all ethics must be in compliance with the data protection provisions set out in the EU General Data Protection Regulation (GDPR) and the Federal Data Protection Act (BDSG). The ethics of the KiGGS baseline study (No. 101/2000) and KiGGS Wave 1 (No. EA2/058/09) have been evaluated by Charité—Universitätsmedizin Berlin's ethics committee. In addition, Hannover Medical School's ethics committee have assessed KiGGS wave 2 (no. 2275-2014); approval from both committees have been collected for the respective studies.

**Informed Consent Statement:** Participation in the studies was voluntary and informed consent was obtained from all subjects participating in the study and/or their parents, if appropriate.

**Data Availability Statement:** We received the raw data from the Robert Koch Institute. The extracted data backing up the findings of the current analyses are accessible from the first author (P.G.) on request.

**Acknowledgments:** We are thankful to the KiGGS study participants and their families. The authors gratefully thank the KiGGS study team from the Robert Koch Institute for providing us with their data file. The authors wish to express their thanks for the financial support of the Open Access Publication Fund of the University of Göttingen for providing the publication fees.

**Conflicts of Interest:** The authors declare no conflict of interest.

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## 3.2 Original Article 2

Ganjeh, P., Hagmayer, Y., Meyer, T., Kuhnert, R., Ravens-Sieberer, U., von Steinbuechel, N., Rothenberger, A. and Becker, A. (2022). Physical activity and the development of general mental health problems or attention-deficit hyperactivity disorder (ADHD) symptoms in children and adolescents: A cross-lagged panel analysis of long-term follow-up epidemiological data. Front. Behav. Neurosci. 16:933139. doi: 10.3389/fnbeh.2022.933139

frontiers | Frontiers in Behavioral Neuroscience

TYPE Original Research
PUBLISHED 13 September 2022
DOI 10.3389/fnbeh.2022.933139



OPEN ACCESS

EDITED BY
Iris Manor,
Geha Mental Health Center, Israel

REVIEWED BY
Clifford Cassidy,
University of Ottawa, Canada
Francisco Xavier Castellanos,
Grossman School of Medicine (NYU),
United States

*CORRESPONDENCE
Parisa Ganjeh
parisa.ganjeh@med.uni-goettingen.de

†These authors share senior authorship

SPECIALTY SECTION
This article was submitted to Pathological Conditions, a section of the journal Frontiers in Behavioral Neuroscience

RECEIVED 30 April 2022
ACCEPTED 08 August 2022
PUBLISHED 13 September 2022

CITATION
Ganjeh P, Hagmayer Y, Meyer T, Kuhnert R, Ravens-Sieberer U, von Steinbuechel N, Rothenberger A and Becker A (2022) Physical activity and the development of general mental health problems or attention-deficit hyperactivity disorder (ADHD) symptoms in children and adolescents: A cross-lagged panel analysis of long-term follow-up epidemiological data. *Front. Behav. Neurosci.* 16:933139. doi: 10.3389/fnbeh.2022.933139



# Physical activity and the development of general mental health problems or attention-deficit hyperactivity disorder (ADHD) symptoms in children and adolescents: A cross-lagged panel analysis of long-term follow-up epidemiological data

Parisa Ganjeh[1]*, York Hagmayer[2], Thomas Meyer[3], Ronny Kuhnert[4], Ulrike Ravens-Sieberer[5], Nicole von Steinbuechel[6], Aribert Rothenberger[1†] and Andreas Becker[1†]

[1]Department of Child and Adolescent Psychiatry and Psychotherapy, University Medical Center Göttingen, Göttingen, Germany, [2]Department of Cognitive Science and Decision Psychology, Georg-Elias-Müller-Institute for Psychology, University of Göttingen, Göttingen, Germany, [3]Department of Psychosomatic Medicine and Psychotherapy, University Medical Center Göttingen, Göttingen, Germany, [4]Unit Mental Health, Department of Epidemiology and Health Monitoring, Robert Koch Institute, Berlin, Germany, [5]Department of Child and Adolescent Psychiatry, Psychotherapy and Psychosomatics, University Medical Center Hamburg-Eppendorf, Hamburg, Germany, [6]Institute of Medical Psychology and Medical Sociology, University Medical Center Göttingen, Göttingen, Germany

Studies have shown that physical activity (PA) can provide a helpful, low-risk, and cost-effective intervention for children and adolescents suffering from mental health problems. This longitudinal study aimed to assess whether PA prevents the development of mental health problems, such as attention-deficit/hyperactivity disorder (ADHD) in children and adolescents. Data were analyzed from the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) collected from more than 15.000 children and adolescents at three different time points over a period of more than 10 years. Parents scored the PA of the study participants on three frequency levels according to WHO recommendations, and mental health problems were assessed by means of the Strengths and Difficulties Questionnaire (SDQ). The total problem score (SDQ-Total) and the hyperactivity/inattention symptoms sub-scale (SDQ-H/I) were used in an autoregressive cross-lagged model to examine their relationship with PA. The results showed that PA of boys and girls at preschool age was inversely associated with the occurrence of mental health problems and, in particular, ADHD symptoms about 6 years later.

Higher levels of PA were associated with better general mental health and fewer ADHD symptoms at the next time point (Wave 1). These effects were not observed from preadolescence (Wave 1) to adolescence (Wave 2), neither for girls nor for boys. These findings indicate that medium-to-high PA may be a supportive factor for good mental health in children in preschool and elementary school. Future studies will have to show whether PA may be a helpful add-on for interventional programs for improving general mental health and alleviating ADHD symptoms among children and adolescents.

KEYWORDS

**physical activity, mental health problems, ADHD, longitudinal relationship, children, adolescents**

## Introduction

Based on the report of the World Health Organization (WHO), mental health disorders will be the primary cause of disease burden by 2030 (World Health Assembly, 2012). It is estimated that about 10% of children and adolescents have one or more mental health conditions (World Health Organization, 2021). According to the German Robert Koch Institute, about 20% of children and adolescents showed signs of mental health problems between 2003 and 2007 and 17% between 2014 and 2017 (Klipker et al., 2018). These conditions can have adverse implications on social and educational skills, productivity (World Health Organization, 2021), and disabilities (Erskine et al., 2015). These conditions remain stable at best or become more severe later in life (Doering et al., 2019; Khan and Burton, 2021). Epidemiological research is needed to find better ways to improve mental health in children and adolescents.

Physical activity (PA) may be a promising factor within this context (Larun et al., 2006; Brown et al., 2013; Wu et al., 2017; Bélair et al., 2018; Bell et al., 2019; Biddle et al., 2019; Parker et al., 2019; Andermo et al., 2020; Ma et al., 2020; Pascoe et al., 2020; Wegner et al., 2020; Bourke et al., 2021; Heinze et al., 2021; Yang et al., 2021). Systematic reviews and meta-analyses showed positive effects of PA on mental health (Wilson and Barnett, 2020; Brylka et al., 2021; Carter et al., 2021). Even during the COVID-19 pandemic, studies showed that PA can be a protective factor against psychological problems among children and adolescents. In their rapid systematic review, Wolf et al. demonstrated a 12–32% and a 15–34% lower hazard ratio for depression and anxiety, respectively, among those who engaged in regular PA with higher frequency during COVID-19 (Wolf et al., 2021). A number of studies from China and the USA. reported that children and adolescents, who engaged in more PA during the pandemic, reported fewer behavioral problems, mental health problems (both externalizing and internalizing), and negative mood states including tension, depression, anger, fatigue, and confusion (Zhang et al., 2020; Liu et al., 2021; Qin et al., 2021; Tandon et al., 2021).

Whereas temporal or cause-effect relationships between variables cannot be inferred from cross-sectional studies, intervention and longitudinal studies may be appropriate to provide some insight into the likely causality or temporality of the role of PA in preventing mental health problems. Given the above-mentioned findings for a positive effect of PA on mental health, it would be unethical to include a control group with extremely low levels or even without PA for an extended period of time in a randomized controlled trial. Indeed, the design of acceptable control groups in this domain is controversial (Lawlor and Hopker, 2001; Schuch et al., 2016). As an alternative, observational studies with a longitudinal design and an adequate statistical approach (especially cross-lagged models) seem to be more acceptable and still informative.

Several longitudinal studies showed a long-term relationship between PA and psychological constructs, but the results are inconsistent (Wu et al., 2018, 2021; Doré et al., 2019, 2020; Kleppang et al., 2019; Loewen et al., 2019; Gómez-Baya et al., 2020; Hamer et al., 2020; Isaksson et al., 2020; Kandola et al., 2020; van Woudenberg et al., 2020; Bowe et al., 2021). To illustrate some results, Nigg et al. concluded that PA may not be a preventive component for mental health problems, but mental health problems can be a risk factor for lower activity at preadolescent ages (Nigg et al., 2021). The authors created a path panel prediction model using MOMO (Motorik-Modul) data (self-reported data from 686 adolescents aged 11–17 years) of the German KiGGS study and found that PA at Baseline positively predicted prosocial behavior at the next time point exclusively among boys. The inverse result was found for girls. Mental health problems at Baseline negatively predicted PA at the second time point among boys and girls. PA at the third time point was predicted by mental health problems at the second time point only among girls. In another cohort study, the PA in 928 adolescents aged 12–13 had a positive association with the emotional sub-scale of the SDQ, but not with the total

difficulties score and mental well-being 3 years later (Bell et al., 2019). Moreover, some studies reported no or inverse sequential association between PA and mental health problems (Hinkley et al., 2017; Ahn et al., 2018; Kleppang et al., 2019; Gómez-Baya et al., 2020). These inconsistencies demand more empirical research to give a clearer picture of the relationship between PA and the development of later mental health problems.

Attention-deficit/hyperactivity disorder (ADHD) is one of the most common neurodevelopmental disorders (Thapar et al., 2017). The global prevalence of ADHD is around 5% (Posner et al., 2020), and it has been reported in up to 7.2% among children and adolescents (Thomas et al., 2015). In Germany, the prevalence rate in children and adolescents was 5.3% (2003–2006) and 4.4% (2014–2017), respectively (Göbel et al., 2018). Age-inappropriate behaviors, including hyperactivity, impulsivity, and inattention, which persist for at least 6 months, are primary ADHD symptoms (American Psychiatric Association, 2016). ADHD has negative effects on social and academic competence, along with a higher risk of mental illness, delinquency (American Psychiatric Association, 2016), and occupational impairment (Erskine et al., 2016). If children with ADHD do not receive effective and timely intervention, at least 60–70% will carry symptoms and psychosocial problems into adulthood (Wilens and Spencer, 2010; Groß et al., 2015; Banaschewski et al., 2017). Given that established treatments for ADHD (i.e., behavior therapy and/or medication) cannot address the whole range of problems, alternative and/or supplementary interventions should be looked for (Rommel et al., 2015; Vysniauske et al., 2020; Welsch et al., 2021).

A growing number of studies provide information that PA may be a promising factor within a treatment program for ADHD symptoms (Halperin et al., 2014; Khalife et al., 2014; Cerrillo-Urbina et al., 2015; Rommel et al., 2015; Ng et al., 2017; Ahn et al., 2018; Wu et al., 2018, 2021; Biddle et al., 2019; Neudecker et al., 2019; Miklós et al., 2020; Vysniauske et al., 2020; Mercurio et al., 2021). Biddle et al. concluded from systematic reviews and meta-analyses that PA leads to better cognitive results and academic achievement (Biddle et al., 2019). Congruent with this conclusion, some studies showed an association between PA and executive and cognitive functions (van der Niet et al., 2015; Xiong et al., 2017; Erickson et al., 2019; Takacs and Kassai, 2019; Xue et al., 2019). Interestingly, in a systematic review and meta-analysis of four non-pharmacological treatments for cognitive problems in ADHD (neurofeedback, cognitive-behavioral therapy, cognitive training, and physical exercises) among 19 selected studies, physical exercise had the highest effect size (Morris d=0.93) among children, adolescents, and adults (Lambez et al., 2020).

A recent study indicated a stronger and more long-lasting improvement in executive functions and behavioral symptoms in children with ADHD when PA was combined with cognitive tasks (Nejati and Derakhshan, 2021). The latest systematic review and meta-analysis also found an improvement in executive functions in 664 children and adolescents with ADHD through exercise intervention (Liang et al., 2021). Significant moderate-to-large effects were reported for inhibitory control and cognitive flexibility. The intensity of exercises and whether the sessions are acute or chronic impacted the results more than the type of exercise. The results of another systematic review showed positive effects of a 1-h long PA and short duration activities on attention as well as on-task behaviors (Ruhland and Lange, 2021). However, when Seiffer et al. investigated the efficacy of PA on children with ADHD, they observed that moderate-to-vigorous PA (MVPA) had only a small effect on total ADHD core symptoms (Seiffer et al., 2021). Another study also found that there were only small improvements in inhibitory control when PA was combined with cognitive training patterns (Dhir et al., 2021).

Adherence to PA is one of the lifestyle recommendations for ADHD children and adolescents. It was linked to fewer physician visits in a longitudinal study with 3,436 participants (Loewen et al., 2020). Pagani and co-authors showed in a study with 758 girls and 733 boys that participating in an extracurricular sport program between ages 6 and 10 was a significant predictor for lower ADHD symptoms at the age of 12 years in girls, but not in boys (Pagani et al., 2020). In a longitudinal study of a community sample of 232 monozygotic twin pairs, greater weekly energy expenditure in terms of activities in adolescence was significantly associated with lower levels of ADHD symptoms in early adulthood (Rommel et al., 2015). Higher levels of PA or engaging in PA were not related to conduct and behavioral problems, anxiety, and ADHD symptoms in a 3-year follow-up study of adolescents (Isaksson et al., 2020) and a prospective study (Peralta et al., 2018). Similarly, other studies did not report a significant effect of PA on ADHD symptoms or executive functions in ADHD children (Smith et al., 2019; Zang, 2019). Brandt et al. even reported that higher moderate activity at age 7 ($n$ = 5,251) was positively associated with ADHD symptoms at age 14 (Brandt et al., 2021). Another study found that objectively measured PA at any intensity was associated with higher hyperactivity scores in boys and girls (Griffiths et al., 2016). Similar findings were reported in a longitudinal study using questionnaire-reported PA (Wiles et al., 2008).

Reviews and meta-analyses typically face some limitations, such as a small number of studies (Biddle et al., 2019; Schuch et al., 2019; Andermo et al., 2020; Lambez et al., 2020; Carter et al., 2021; Liang et al., 2021), differences in methodologies (Lambez et al., 2020; Vysniauske et al., 2020; Dhir et al., 2021; Seiffer et al., 2021), differences between studies in assessing PA and mental health outcomes (Biddle et al., 2019; Andermo et al., 2020; Liang et al., 2021; Ruhland and Lange, 2021; Welsch et al., 2021), studies with low or moderate quality and high risk of bias (Rodriguez-Ayllon et al., 2019; Vysniauske et al., 2020; Carter et al., 2021; Dhir et al., 2021; Seiffer et al., 2021; Welsch et al., 2021), and non-representative samples (Biddle et al., 2019;

Rodriguez-Ayllon et al., 2019; Vysniauske et al., 2020; Bourke et al., 2021; Liang et al., 2021; Welsch et al., 2021). Individual studies have small and non-representative samples (Ahn et al., 2018; Bowe et al., 2021; Mercurio et al., 2021), low quality, no long-term follow-ups, and inadequate consideration of real-world implementation factors for intervention studies (Parker et al., 2019). In many longitudinal studies, there is a lack of repeated measurements of either PA or mental health outcomes (Ahn et al., 2018; Peralta et al., 2018; Bell et al., 2019; Doré et al., 2019, 2020; Kleppang et al., 2019; Hamer et al., 2020; Pagani et al., 2020; van Woudenberg et al., 2020; Bowe et al., 2021; Wu et al., 2021). Also, a focus on specific mental health outcomes (Rodriguez-Ayllon et al., 2019) and less frequent use of multidimensional measurements (Bell et al., 2019) are further limitations that should be mentioned.

Due to the heterogeneity of findings and the limitations outlined above, it has not been possible to reach a firm conclusion so far. Hence, there is still a need for methodologically sound, large-scale, representative, longitudinal studies (Kleppang et al., 2019; Bowe et al., 2021; Neville et al., 2021; Wu et al., 2021). The study presented in this article tries to overcome most of the aforementioned limitations. It has the following advantages: a large sample of children and adolescents (including boys and girls), and a measurement of PA and mental health problems at three time points over 10 years using a psychometrically valid multidimensional inventory (SDQ) for evaluating general mental health problems as well as ADHD symptoms. The results will provide further empirical evidence on the temporal relationships between PA and mental health problems. They will thus highlight possible causal pathways and will give directions for practical applications. Based on the findings, which indicated a positive effect of PA on mental health problems for children, we expected to find an effect of early PA on later mental health problems in general mental health problems and, in particular, symptoms of ADHD.

# Materials and methods

## Study design

This study is based on data from the German Health Interview and Examination Survey for Children and Adolescents (KiGGS), which was conducted by the Robert Koch Institute. The purpose and design of the KiGGS study have been described in detail in other reports (Kamtsiuris et al., 2007; Kurth et al., 2008; Hölling et al., 2012). The study complied with the EU General Data Protection Regulation (GDPR) and the Federal Data Protection Act (BDSG). Ethics for the KiGGS Baseline (No. 101/2000) and Wave 1 (No. EA2/058/09) have been approved by the Charité Universitätsmedizin Berlin's ethics committee. KiGGS Wave 2 (No. 2275-2014) was evaluated and approved by Hannover Medical School's ethics committee. Informed consent was obtained from all individual participants and/or their parents.

Data were collected in three waves, covering the intervals from 2003 to 2006 (Baseline), 2009 to 2012 (Wave 1), and 2014 to 2017 (Wave 2). At Baseline, 17,641 children and adolescents (8,656 girls and 8,985 boys) aged 0 to 17 years participated along with their parents. Participants were randomly chosen through a stratified sampling method at 167 study sites scattered throughout Germany. The response rate was 66 and 67% for boys and girls, respectively. The first follow-up survey (Wave 1) was conducted after a gap of about 6 years in the form of a telephone questionnaire survey. For this wave, 11,992 (68%) of the Baseline participants were re-invited and participated in the study (Mauz et al., 2019). In Wave 2, 15,023 children and adolescents aged between 0 and 17 years took part in a cross-sectional and longitudinal sample. In the longitudinal sample of Wave 2, there were 10,853 girls and boys (with a response rate of 61.5%) (Kurth, 2018). Figure 1 (Hoffmann et al., 2018) presents the longitudinal sample sizes of the KiGGS study.

## Assessment of physical activity

At Baseline, PA was a composite variable derived from several questions about the frequency of participation in different sports and other physical activities by children and adolescents. Data for PA were taken from parents of 0- to 10-year-old children and teenagers (11–17 years old). Three ordered categories of PA were computed from the responses, namely 1 = low, 2 = medium, and 3 = high. The WHO's recommendations (World Health Organization, 2010) for PA were taken into account for the assessments in Wave 1 and Wave 2. Parents and teenagers were asked: "How many days is your child (are you) at least 60 min physically active during a normal week?". Responders could choose between 0 = never and 7 = all weekdays. For a better comparison between time points, three categories of PA were also defined for the responses at Waves 1 and 2 also, namely: low = never to 2 days per week, medium = 3–5 days per week, and high = 6–7 days per week. Hence, for all three time points, PA was an ordered categorical variable with three levels (low, medium, and high).

According to the study protocol, PA represents a mixed report variable, because it was assessed by parents (for 0- to 10-year-old children) and teenagers (for 11- to 17-year-old adolescents). This decision was made because adolescents are more reliable in providing behavioral information about themselves than younger children due to their matured ability to recall memories and self-perception. Moreover, researchers found a low agreement between parents' reports and adolescents' reports of PA (Sithole and Veugelers, 2008; Reichert et al., 2010; Koning et al., 2018), and agreements were usually related to organized PA (Poulain et al., 2020). Hence, the use of mixed reports of PA in this study seems to be justified.

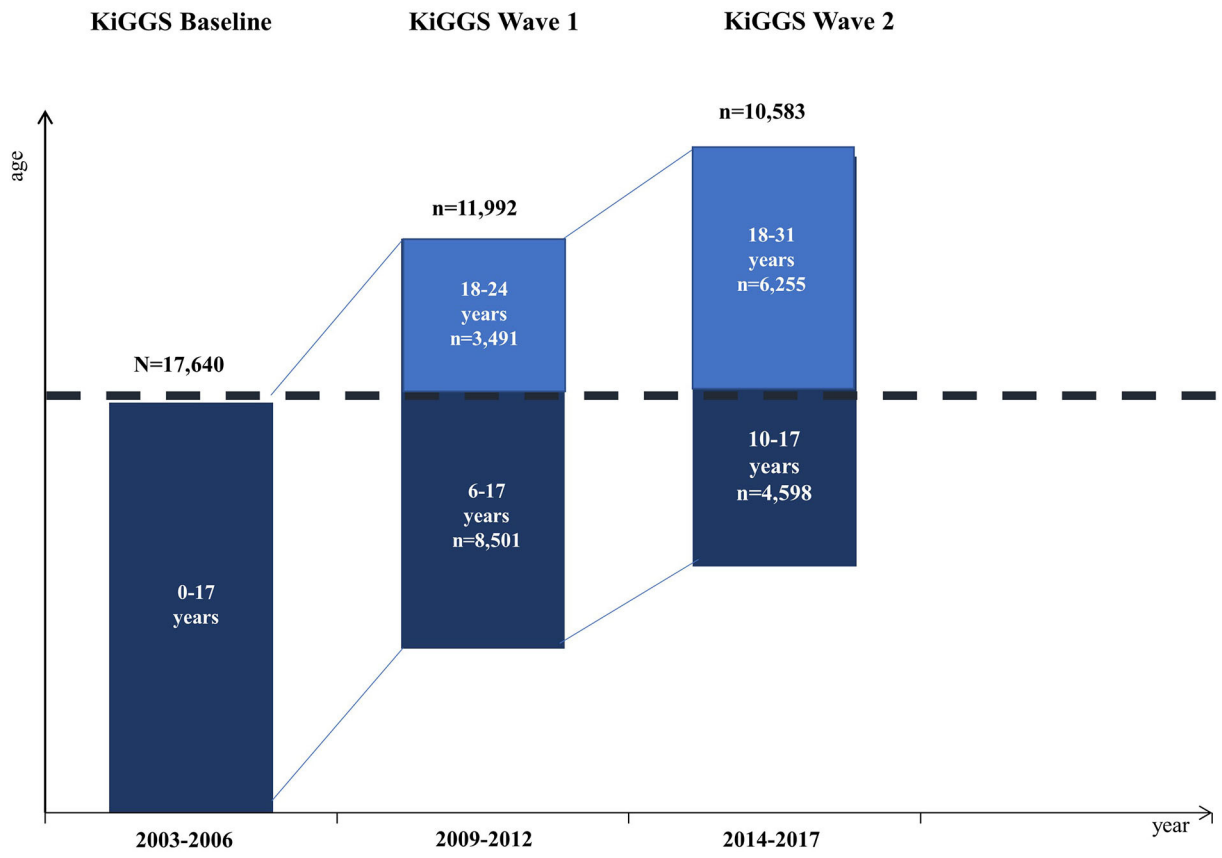


FIGURE 1
Longitudinal sample sizes of the KiGGS study. Dark blue bars: Longitudinal data from study participants not older than 17 years (the data used for analyses in this study). Light blue bars: Longitudinal data at Wave 1 and Wave 2 older than 17 years.

## Mental health problems and ADHD symptoms

The KiGGS study assessed mental health by the Strength and Difficulties Questionnaire through parent- and self-report (Goodman, 1997). The SDQ is comprised of 25 items which present statements to be rated on a scale from 0 = not true to 2 = certainly true. The SDQ has five sub-scales: emotional problems, conduct problems, hyperactivity/inattention, peer problems, and prosocial behavior. The scores within these sub-scales range from 0 to 10. The total difficulties score is calculated by adding the scores of the sub-scales except for the prosocial behavior scale. A higher score indicates a higher grade of difficulties. For this study, the total difficulties score and the hyperactivity/inattention score (SDQ-H/I) taken from the parent report (for children between 3 and 17 years old) were used as an indicator for general mental health problems and symptoms of ADHD, respectively. Psychometric properties of the SDQ were investigated in normal (Klasen et al., 2000) and clinical (Becker et al., 2004) samples of German children and adolescents. The outcome scores are reliable and significantly correlated with the Child Behavior Checklist (CBCL). The questionnaire was shown to be a valid instrument to identify psychiatric patients and other disorder categories (Klasen et al., 2000; Becker et al., 2004). In this study, Cronbach's alphas for the total score of SDQ and the SDQ-H/I sub-scale were 0.80 and 0.76, respectively.

## Covariates

Parental socioeconomic status (SES) (Lampert et al., 2014) and the participant's sex, age, and body-mass index (BMI) were used as covariates in the analyses. These were chosen based on preceding studies, which indicated that they were the most important covariates (Rommel et al., 2015; Hinkley et al., 2017; Ahn et al., 2018; Bell et al., 2019; Doré et al., 2019, 2020; Kleppang et al., 2019; Schuch et al., 2019; Zhang et al., 2020; Bowe et al., 2021; Brandt et al., 2021).

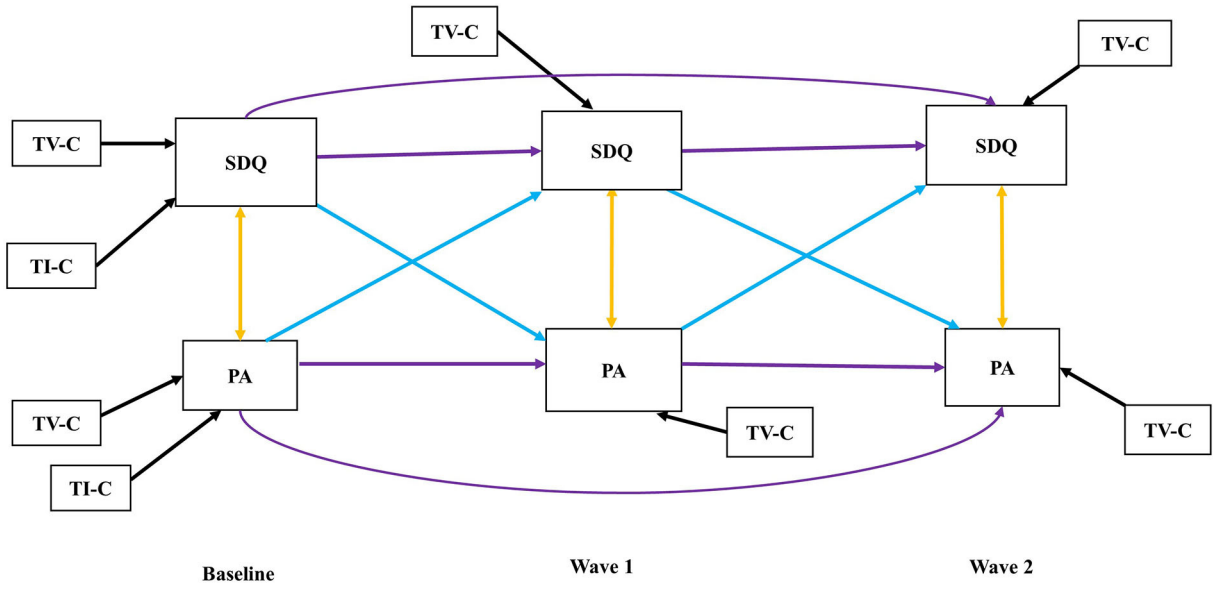


FIGURE 2
Autoregressive cross-lagged model. TV-C: Time-variant covariate, TI-C: Time-invariant covariate, Purple arrows: Auto-regressive paths, Blue arrows: Cross-lagged paths, Yellow arrows: Cross-sectional paths, Black arrows: Covariate paths, SDQ: Indicating SDQ-Total for the first model as well as SDQ-H/I for the second model at Baseline, Wave 1, and Wave 2, respectively.

## Statistical analyses

For longitudinal analyses of the bi-directional relations between PA and either mental health problems or ADHD symptoms, autoregressive cross-lagged panel models were used. All statistical analyses were conducted in R using the lavaan package (R Core Team, 2020). The pairwise deletion method was used to handle missing values. This method of handling missing data appears to be the best possible strategy, when a categorical variable (PA) is included in the analyses[1].

Cross-lagged path models allow for the estimation of cross-lagged effects, controlling for correlations within time points, and controlling for the stability of variables over time by considering autoregressive effects. Moreover, these models can provide preliminary evidence for causality (Kearney, 2017). The cross-lagged panel model in this study includes two constructs measured at three time points (Baseline, Wave 1, and Wave 2) (Figure 2). To investigate the longitudinal reciprocal relationship between PA and general mental health using the total SDQ score and hyperactivity/inattention symptoms (SDQ-H/I), we evaluated several nested models by adding paths and controlling for parental socioeconomic status as a time-invariant and participant's body-mass index (BMI) as a time-variant covariate. Sex was used as a grouping variable. The non-significant paths were not deleted in the final model. The estimation method of the model parameters was diagonally weighted least square (DWLS). Nested models were compared using likelihood ratio tests and fit indices (CFI, TLI, and RMSEA). The robust versions of these indices were used. Because of the findings presented above, which predict the presence of cross-lagged paths and an influence of the covariates, we decided to use the full model to test the hypothesis, if the full model had an acceptable fit to the data. For testing, the statistical significance level was set to 0.05, which was adjusted to 0.025, because the coefficient for the relation between PA and SDQ, as well as PA and SDQ-H/I was tested twice (Baseline to Wave 1 and Wave 1 to Wave 2).

1 https://rdrr.io/cran/lavaan/man/lavOptions.html

# Results

## Sample

The total sample at Baseline was 17,640 children and adolescents (8,654 girls and 8,986 boys) aged 0 −17 years. Due to the method used for handling missing data, the analysis was run with 17,638 participants (8,985 boys and 8,653 girls). We used data for children and adolescents up to 17 years old (see dark blue bars in Figure 1), because parent-reported SDQ data were only available up to this age. The exact numbers and descriptive characteristics of the longitudinal sample at Baseline, Wave 1, and Wave 2 are shown in Table 1. Note that the number of participants declines across the three waves due to participants dropping out. The correlation matrix for the variables at the three

time points can be found in Supplementary Table 1 in Appendix A.

## Longitudinal autoregressive cross-lagged model

### Cross-lagged models for the relationship of PA and SDQ-Total

Fit indices of the three nested models can be found in Table 2. The model fit indices of Model 3 were good (CFI = 0.95, TLI = 0.90, RSMEA = 0.031). The fit indices of Model 2, which excludes the covariates, were almost perfect (CFI > 0.99, TLI = 0.99, RSMEA = 0.008). Nevertheless, we continued with Model 3, which includes all cross-lagged paths and the covariates, because of our hypothesis and previous research, which found the covariates to be relevant. In Table 3, the results for the statistically significant path coefficients of Model 3 including autoregressive paths, adjacent cross-lagged paths, and covariates are shown.

Among boys, the autoregressive paths between adjacent and distant time points were significant for SDQ and for adjacent paths also for PA. The stability of mental health problems decreased for the autoregressive paths over time ($beta_{Baseline-Wave1}$ = 0.548 to $beta_{Wave1-Wave2}$ = 0.424 for SDQ), whereas the stability of PA increased for the autoregressive paths over time ($beta_{Baseline-Wave1}$ = 0.049 to $beta_{Wave1-Wave2}$ = 0.254) (Table 3). The cross-sectional correlations between PA and SDQ were negative and significant (*rs* ranged from −0.549 to −0.276).

Among girls, the autoregressive paths between adjacent and distant time points were significant for SDQ and PA (only one adjacent path). The stability of mental health problems decreased slightly for the adjacent autoregressive paths over time ($beta_{Baseline-Wave1}$ = 0.536 to $beta_{Wave1-Wave2}$ = 0.478) for SDQ, whereas the stability of PA increased for the autoregressive paths over time ($beta_{Baseline-Wave1}$ = −0.004 to $beta_{Wave1-Wave2}$ = 0.161) (Table 3). The cross-sectional correlation between PA and SDQ was only significant at Baseline (*rs* = −0.295).

The cross-lagged path from PA at Baseline to SDQ at Wave 1 was significant and negative for boys and girls (beta = −0.329 and beta = −0.233). Thus, higher PA at Baseline was associated with lower mental health problems score at Wave 1. Moreover, reciprocally, there was a negative significant association between SDQ at Baseline with PA at Wave 1 (beta = −0.012, $p < 0.01$) among boys. Considering the adjusted significance level of 0.025, the association between SDQ at Wave 1 and PA at Wave 2 (beta = −0.011, *P*-value = 0.043) was not significant among girls.

TABLE 1 Descriptive characteristics of the study population at Baseline, Wave 1, and Wave 2.

| | | *N* | Mean | SD | Min | Max |
|---|---|---|---|---|---|---|
| **Baseline** | | | | | | |
| Sex | Boys | 8,986 (50.9%) | | | 1 | 2 |
| | Girls | 8,654 (49.1%) | | | | |
| | Total | 17,640 | | | | |
| Age (years) | | 17,640 | 8.51 | 5.07 | 0 | 17 |
| SDQ-emotion | | 14,497 | 1.78 | 1.80 | 0 | 10 |
| SDQ-behavioral problems | | 14,502 | 1.93 | 1.53 | 0 | 9 |
| SDQ-hyperactivity inattention | | 14,498 | 3.14 | 2.27 | 0 | 10 |
| SDQ-peer problems | | 14,496 | 1.44 | 1.61 | 0 | 8 |
| SDQ-prosocial behavior | | 14,529 | 7.80 | 1.72 | 1 | 10 |
| SDQ-Total | | 14,477 | 8.29 | 5.15 | 0 | 32 |
| Physical activity | Low | 6,005 (36.1%) | | | 1 | 3 |
| | Medium | 5,422 (32.6%) | | | | |
| | High | 5,221 (29.6%) | | | | |
| | Total | 16,648 | | | | |
| Socioeconomic status | | 17,306 | 11.65 | 3.84 | 3 | 21 |
| Body-mass index (kg/m$^2$) | | 17,493 | 18.23 | 3.64 | 10.84 | 33.08 |
| **Wave 1** | | | | | | |
| Age (years) | | 8,501 | 11.73 | 3.385 | 6 | 17 |
| SDQ-emotion | | 8,441 | 1.95 | 1.84 | 0 | 9 |
| SDQ-behavioral problems | | 8,442 | 1.94 | 1.52 | 0 | 9 |
| SDQ-hyperactivity inattention | | 8,440 | 2.94 | 2.18 | 0 | 10 |
| SDQ-peer problems | | 8,439 | 1.29 | 1.49 | 0 | 8 |
| SDQ-prosocial behavior | | 8,440 | 8.35 | 1.55 | 0 | 10 |
| SDQ-Total | | 8,436 | 8.12 | 4.96 | 0 | 31 |
| Physical activity | Low | 1,694 (20.8%) | | | 1 | 3 |
| | Medium | 4,105 (50.4%) | | | | |
| | High | 2,351 (28.8%) | | | | |
| | Total | 8,150 | | | | |
| Body-mass index (kg/m$^2$) | | 7,234 | 18.49 | 3.66 | 10.27 | 34.89 |
| **Wave 2** | | | | | | |
| Age (years) | | 4,598 | 14 | 1.99 | 10 | 17 |
| SDQ-emotion | | 4,508 | 1.70 | 1.85 | 0 | 10 |
| SDQ-behavioral problems | | 4,512 | 1.54 | 1.43 | 0 | 8 |
| SDQ-hyperactivity inattention | | 4,511 | 2.57 | 2.06 | 0 | 10 |
| SDQ-peer problems | | 4,507 | 1.32 | 1.60 | 0 | 8 |
| SDQ-prosocial behavior | | 4,508 | 8.01 | 1.73 | 1 | 10 |
| SDQ-Total | | 4,502 | 7.13 | 4.90 | 0 | 28 |
| Physical activity | Low | 1,214 (27.8%) | | | 1 | 3 |
| | Medium | 2,173 (49.8%) | | | | |
| | High | 980 (22.4%) | | | | |
| | Total | 4,367 | | | | |
| Body-mass index (kg/m$^2$) | | 3,592 | 20.84 | 4.006 | 12.06 | 40.025 |

Based on Model 3, estimated means of the total score of the SDQ and their 90% confidence intervals were computed. These are shown in Table 4. These means illustrate the positive effect of PA on both boys and girls.

TABLE 2 Models of the reciprocal relations between PA and SDQ-Total.

| Model | | $\chi^2$ | | *df* | *p* | CFI | TLI | RMSEA [90% CI] |
|---|---|---|---|---|---|---|---|---|
| | | Boys | Girls | | | | | |
| Model 1 | Autoregressive model with adjacent and distant paths | 29.052 | 23.041 | 12 | 0.001 | 0.992 | 0.98 | 0.020 [0.014–0.025] |
| Model 2 | Adding adjacent cross-lagged paths | 2.862 | 3.169 | 4 | 0.334 | 1 | 0.99 | 0.008 [0.00–0.019] |
| Model 3 | Adding covariates paths | 190.306 | 154.802 | 36 | 0.000 | 0.95 | 0.90 | 0.031 [0.028–0.034] |

TABLE 3 Significant paths coefficients of Model 3 between PA and SDQ-Total.

| Group | Boys | Girls |
|---|---|---|
| **Paths from…to….** | **Beta (Std.Err)/P value** | **Beta (Std.Err)/P value** |
| Autoregressive paths | | |
| SDQ0 to SDQ2 | 0.225 (0.027)** | 0.165 (0.025)** |
| SDQ0 to SDQ1 | 0.548 (0.013)** | 0.536 (0.013)** |
| SDQ1 to SDQ2 | 0.424 (0.021)** | 0.478 (0.20)** |
| PA0 to PA1 | 0.049 (0.021)$^{+}$ | −0.004 (0.020) |
| PA1 to PA2 | 0.254 (0.026)** | 0.161 (0.029)** |
| Cross-lagged paths | | |
| PA0 to SDQ1 | −0.329 (0.091)** | −0.233 (0.085)* |
| SDQ0 to PA1 | −0.012 (0.004)* | −0.006 (0.004) |
| SDQ1 to PA2 | −0.009 (0.005) | −0.011 (0.005) |
| Cross-sectional paths | | |
| SDQ0 to PA0 | −0.549 (0.070)** | −0.295 (0.063)** |
| SDQ1 to PA1 | −0.164 (0.077) $^{+}$ | 0.060 (0.072) |
| SDQ2 to PA2 | −0.276 (0.103)* | −0.120 (0.092) |

PA0 and SDQ0 = measured at Baseline, PA1 and SDQ1 = measured at Wave 1, and PA2 and SDQ2 = measured at Wave 2. **p < 0.001, *p < 0.01, $^{+}$p < 0.05.

TABLE 4 Estimated means of SDQ-Total at Wave 1 in different levels of PA at baseline.

| | Boys | Girls |
|---|---|---|
| | **SDQ-Total mean (SE) [90% CI]** | |
| Physical activity | | |
| Low | 8.79 (0.17) [8.44–9.14] | 7.78 (0.16) [7.47–8.10] |
| Medium | 8.49 (0.13) [8.22–8.76] | 7.51 (0.12) [7.26–7.75] |
| High | 8.24 (0.12) [7.99–8.49] | 7.39 (0.13) [7.12–7.66] |

## Cross-lagged models for the relationship of PA and SDQ-H/I

Table 5 presents fit indices for the three nested models calculated to investigate the longitudinal relationship between PA and ADHD symptoms, as determined by the SDQ-H/I scores. Model 3 included all potential paths, and its model fit indices were considered to be good. The results of this model including autoregressive paths, adjacent cross-lagged paths, and covariates are reported in Table 6.

For boys, the autoregressive paths between adjacent and distant time points were significant for hyperactivity/inattention and PA (only in adjacent paths). The stability of SDQ-H/I decreased slightly for the autoregressive paths over time ($beta_{Baseline-Wave1} = 0.521$ to $beta_{Wave1-Wave2} = 0.495$) for SDQ-H/I, whereas the stability of PA increased for the autoregressive paths over time ($beta_{Baseline-Wave1} = 0.056$ to $beta_{Wave1-Wave2} = 0.259$) (Table 6). The cross-sectional correlation between PA and SDQ-H/I was only significant at Baseline ($rs = -0.067$).

For girls, the autoregressive paths between adjacent and distant time points were significant for SDQ-H/I and PA (only in one adjacent path). The stability of SDQ-H/I symptoms decreased for the autoregressive paths over time ($beta_{Baseline-Wave1} = 0.519$ to $beta_{Wave1-Wave2} = 0.457$), whereas the stability of PA increased for the autoregressive paths over time ($beta_{Baseline-Wave1} < 0.001$ to $beta_{Wave1-Wave2} = 0.165$) (Table 6). For girls, there was a small positive cross-sectional correlation between PA and SDQ-H/I symptoms at Wave 1 and Wave 2 ($rs = 0.109$, $p < 0.01$ and $rs = 0.095$, $p < 0.05$, respectively).

The cross-lagged path from PA at Baseline to SDQ-H/I at Wave 1 was significant and negative for boys and girls alike (beta = −0.188 and beta = −0.152). Thus, a higher PA at Baseline was associated with lower symptoms of hyperactivity/inattention at Wave 1. Interestingly, the estimate of the cross-lagged path from PA at Wave 1 to SDQ-H/I at Wave 2 was positive among boys and girls (beta = 0.103, *P*-value = 0.043, beta = 0.017, *P*-value = 0.707). There was a negative significant association between SDQ-H/I at Wave 1 with PA at Wave 2, but only among girls (beta = −0.029, $p < 0.05$). The estimated means of SDQ-H/I are reported for the three categories of PA for cross-lagged path from PA at Baseline and Wave 1 to SDQ-H/I at Wave 1 and Wave 2.

Table 7 shows the means and the 95%-confidence intervals predicted from Model 3. For boys, the estimated means of SDQ-H/I at Wave 1 were higher for a low level of PA. For girls, the

TABLE 5 Models of the reciprocal relations between PA and SDQ-H/I.

| Model | | $\chi^2$ | | *df* | *p* | CFI | TLI | RMSEA [90% CI] |
|---|---|---|---|---|---|---|---|---|
| | | Boy | Girl | | | | | |
| Model 1 | Autoregressive model with adjacent and distant paths | 27.539 | 24.474 | 12 | 0.000 | 0.989 | 0.973 | 0.020 [0.014–0.025] |
| Model 2 | Adding adjacent cross-lagged paths | 4.451 | 3.043 | 4 | 0.22 | 0.999 | 0.993 | 0.010 [0.000–0.021] |
| Model 3 | Adding covariates paths | 208.849 | 192.844 | 36 | 0.000 | 0.933 | Robust: 0.855, Standard: 0.916 | 0.034 [0.031–0.037] |

TABLE 6 Significant paths coefficients of Model 3 between PA and SDQ-H/I.

| Group | Boys | Girls |
|---|---|---|
| **Paths from…to….** | **Beta (Std.Err)/P value** | **Beta (Std.Err)/P value** |
| Autoregressive paths | | |
| SDQ-H/I 0 to SDQ-H/I 2 | 0.119 (0.026)** | 0.099 (0.027)** |
| SDQ-H/I 0 to SDQ-H/I 1 | 0.521 (0.014)** | 0.519 (0.014)** |
| SDQ-H/I 1 to SDQ-H/I 2 | 0.495 (0.022)** | 0.457 (0.021)** |
| PA1 to PA2 | 0.259 (0.026)** | 0.165 (0.029)** |
| PA0 to PA1 | 0.056 (0.021)* | 0.00 (0.20) |
| Cross-lagged paths | | |
| PA0 to SDQ-H/I 1 | −0.188 (0.04)** | −0.152 (0.037)** |
| PA 1 to SDQ-H/I 2 | 0.103 (0.051) | 0.017 (0.046) |
| SDQ-H/I 1 to PA2 | −0.009 (0.012) | −0.029 (0.012) $^{+}$ |
| Cross-sectional paths | | |
| SDQ-H/I 0 to PA0 | −0.067 (0.031)$^{+}$ | 0.023 (0.028) |
| SDQ-H/I 1 to PA1 | 0.025 (0.036) | 0.109 (0.031)** |
| SDQ-H/I 2 to PA2 | 0.019 (0.043) | 0.095 (0.038)$^{+}$ |

PA0 and SDQ-H/I 0 = measured at Baseline, PA1 and SDQ-H/I 1 = measured at Wave 1, and PA2 and SDQ-H/I 2 = measured at Wave 2. **p < 0.001, *p < 0.01, $^{+}$p < 0.05.

TABLE 7 Estimated means of SDQ-H/I for different levels of PA.

| | Means of SDQ-H/I at Wave 1 for the three levels of PA at Baseline | | Means of SDQ-H/I at Wave 2 for the three levels of PA at Wave 1 |
|---|---|---|---|
| | Boys | Girls | Boys |
| | SDQ-H/I mean (SE) [95% CI] | | SDQ-H/I mean (SE) [95% CI] |
| Physical activity | | | |
| Low | 3.33 (0.07) [3.18–3.49] | 2.51 (0.06) [2.38–2.64] | 2.34 (0.14) [2.06–2.63] |
| Medium | 3.20 (0.06) [3.08–3.32] | 2.48 (0.05) [2.38–2.58] | 2.69 (0.08) [2.52–2.85] |
| High | 3.21 (0.05) [3.10–3.32] | 2.37 (0.05) [2.26–2.49] | 2.88 (0.101) [2.68–3.08] |

estimated mean is lower for a high level of PA. At Wave 2, the relation was reversed for boys. The estimated mean SDQ-H/I was lower for low PA. The sample size used was based on the estimated model (Table 7).

# Discussion

Overcoming several limitations of earlier studies, this study is based on a large, longitudinal panel study of children and adolescents enrolled in the German KiGGS study (Kamtsiuris et al., 2007). Data from this study allowed us to examine the reciprocal relationship between PA and general mental health problems, as well as ADHD symptoms. An autoregressive cross-lagged panel model was applied for the three time points investigated: Baseline, Wave 1, and Wave 2. After a control for autoregressive paths, previous mental health problems, and time-variant and time-invariant covariates, PA showed a significant negative relationship with subsequent general mental health problems and ADHD symptoms. Evidence was found for PA at Baseline as a predictor of general mental health problems, as well as ADHD symptoms at Wave 1, that is after about 6 years.

## Longitudinal relationship between PA and general developmental psychopathology

In line with other studies (Doré et al., 2019; Loewen et al., 2019; Gómez-Baya et al., 2020; Wu et al., 2021), the findings indicated that higher levels of PA in childhood can predict

mental health problems 6 years later in both boys and girls. This confirms a general tendency found in several studies with prepubertal children (Hamer et al., 2020). However, for the cross-lagged association from Wave 1 to Wave 2 (i.e., during adolescence), there was no significant path from PA to mental health problems neither for boys nor girls. Only the latter finding is inconsistent with studies that investigated longitudinal relationships between PA and later mental health problems among adolescents (Bell et al., 2019; Doré et al., 2020; Gómez-Baya et al., 2020; Isaksson et al., 2020; Kandola et al., 2020; Bowe et al., 2021). All these studies found that inactivity or low activity was associated with increased emotional difficulties, depressive symptoms (Bell et al., 2019; Gómez-Baya et al., 2020; Kandola et al., 2020; Bowe et al., 2021), and a negative outcome for autonomy, competence, and relatedness perceptions (Doré et al., 2020). The effect of early PA on mental health in the teenage years may be moderated by psychosomatic and psychosocial puberty issues, personality identification, peer problems, BMI development, and a change in sedentary behavior. The samples used in different studies may have deviated from each other with respect to these factors. It is a challenge to control all these factors.

There were significant effects from total SDQ scores at Baseline to PA at Wave 1 among boys. In line with these results, a study found that mental health problems in childhood may be a risk factor for lower preadolescent activity among boys (Nigg et al., 2021). The path coefficients, however, were clearly smaller than the path coefficients from PA to SDQ-Total, which indicates that PA is more predictive of general mental health problems than inversely general mental health problems for PA.

Significant high stability in autoregressive paths was found for both SDQ-Total and PA from Baseline to Wave 2. Adjacent and distant paths were significant for SDQ-Total. This may indicate that individual differences in mental health problems increase over a 10-year period from preschool to adolescence for both sexes reflecting developmental changes from childhood to adolescence. In contrast, only adjacent paths were significant for PA from Baseline to Wave 1 among boys and Wave 1 to Wave 2 in boys and girls. This might be due to different measurements of PA at Baseline and the two subsequent waves (see Limitations).

In summary, the findings provide new evidence for a positive relationship between early PA and later mental health, which may indicate a positive causal relationship between them. PA may be a viable predictor and a preventive factor of mental health problems in children and adolescents.

## Longitudinal relationship between PA and ADHD symptoms

In this study, we observed a temporal and reciprocal relationship between PA and ADHD symptoms. Higher levels of PA in childhood were associated with lower ADHD symptoms 6 years later for boys and girls. This finding is consistent with previous studies which found positive effects of PA on the reduction of ADHD symptoms (Rommel et al., 2015; Loewen et al., 2020; Pagani et al., 2020; Liang et al., 2021) and cognitive performance related to ADHD (Biddle et al., 2019; Lambez et al., 2020; Ruhland and Lange, 2021) among children and adolescents. In this study, the cross-lagged relationship between PA and ADHD symptoms was positive from Wave 1 to Wave 2 among boys and girls. It implies that a higher level of PA was associated with higher levels of ADHD symptoms. Although the effect size was small, other studies have reported similar results (Ganjeh et al., 2021). Three other longitudinal studies found that a 15–30 min increase in PA was associated with higher SDQ-H/I scores (Ahn et al., 2018) and that more PA predicted more ADHD symptoms (Wiles et al., 2008; Brandt et al., 2021). Differentiating between the frequency, duration, and intensity of PA, as well as adding other covariates to the analysis may explain the different findings (Wiles et al., 2008; Brandt et al., 2021; Ganjeh et al., 2021).

Notably, significant cross-lagged effects from ADHD symptoms to PA were found only among girls from Wave 1 to Wave 2. This means that girls with higher levels of ADHD symptoms had lower levels of PA about 4 years later. However, there was no reciprocal path, from PA to ADHD symptoms for girls for these waves. This finding may suggest that PA should be encouraged for teenage girls with severe ADHD to support their mental health. However, more research is required.

Concerning stability, adjacent and distant autoregressive paths were significant and decreased ADHD symptoms. This means that symptoms of this disorder can change during developmental periods, as is known from hyperactivity (Banaschewski et al., 2017). The autoregressive paths of PA were significant only for adjacent paths. The increasing path strengths of PA in the model for ADHD imply that PA has changed little over the 10-year period, specifically among boys. This might be a result of different measurements of PA at Baseline and at the two following waves (see Limitations). However, it seems that other models, for example, growth curve models, may more clearly explain the trajectories of changes over time than does our model. Hence, it is suggested that further studies should investigate trajectories of PA and mental health problems.

# Strengths and limitations

The longitudinal approach with a large sample size of children and adolescents is a strength of this study because it can help to gain information about the causal relationship between PA and general mental health problems, as well as ADHD symptoms. Using SDQ as a valid multidimensional inventory to

evaluate not only the general mental health problems but also ADHD symptoms is another strength of this study. Our sample covers a broad age range from preschool children to adolescents. Furthermore, evaluating PA, general mental health problems, and ADHD symptoms at three time points allows controlling for previous values of these variables in the longitudinal models, thus creating stronger evidence.

Despite the strengths of this study, which overcome some of the shortcomings of previous works, the study did have some limitations. At Wave 1 and Wave 2, we used one core-question to evaluate PA according to the WHO recommendations. Therefore, we had no insight into the physical activities performed (e.g., the type of activity or its intensity). In consequence, we suggest that future studies may use questionnaires and/or objective methods to obtain more detailed information about the kind of PA. Furthermore, PA at Baseline was a composite variable derived from several other more specific variables and was therefore not identical to Wave 1 and Wave 2. This may have contributed to the rather low stability of PA between Baseline and Wave 1 and the substantially higher stability between Wave 1 and 2. Using a mixed report variable of PA, namely parental reports for children up to 11 years of age and self-reports for older children, is another limitation. This decision was justified by findings of low agreement between parent report and self-report of PA for adolescents (Sithole and Veugelers, 2008; Reichert et al., 2010; Koning et al., 2018). There is, however, no direct evidence that a mixed report increases the validity of the measurement of PA. Another limitation was the exclusive use of parent-reported data on mental health problems, although this was methodologically justified for developmental reasons. Finally, our results are not fully representative of the German population because we did not use the appropriate weighting of factors in the analyses.

## Conclusion

The findings of this study provide reliable evidence for the hypothesis that PA has positive effects on later mental health problems, including ADHD symptoms in children but not in adolescents. A higher level of PA at preschool age may lead to lower SDQ scores and ADHD symptoms 6 years later. The effects were stronger for boys than for girls. In conclusion, the findings suggest that weekly medium-to-high PA may be helpful to prevent mental health problems (including ADHD symptoms) in children.

## Data availability statement

The raw data supporting the results of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed by the responsible Ethics Committees. The approval of Robert Koch Institute studies' data protection was received and the compliance of all ethics with the data protection provisions set out in the EU General Data Protection Regulation (GDPR) and the Federal Data Protection Act (BDSG) was confirmed. KiGGS Baseline (No. 101/2000) and Wave 1 (No. EA2/058/09) ethics have been assessed by Charité-Universitätsmedizin Berlin's Ethics Committee. KiGGS Wave 2 (No. 2275-2014) was also evaluated and approved by Hannover Medical School's Ethics Committee. Informed consent was obtained from all individual participants and/or their parents included in the study. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## Author contributions

PG performed the study conception, formal analysis, and the writing of the original draft. PG and YH contributed to the methodology of the study. PG and AR contributed to interpreting the results. Writing—review and editing were conducted by PG, AR, YH, TM, NS, UR-S, RK, and AB. All authors contributed to the article and approved the submitted version.

## Acknowledgments

We thank the participants of the KiGGS study and their families. The authors would like to thank the KiGGS study team from Robert Koch Institute for providing data. We would also like to express our gratitude to the Open Access Publication Fund of the University of Göttingen for supporting the publication fees.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnbeh.2022.933139/full#supplementary-material

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Appendix A

Table 1A. The correlation matrix between variables at three time-points.

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Baseline** | | | | | | | | | | | | |
| SDQ-Emotion (1) | 1 | | | | | | | | | | | |
| SDQ-Behavioral problems (2) | **0.3** (14491) | 1 | | | | | | | | | | |
| SDQ-Hyperactivity inattention (3) | **0.32** (14487) | **0.48** (14491) | 1 | | | | | | | | | |
| SDQ-Peer problems (4) | **0.36** (14484) | **0.3** (14486) | **0.26** (14486) | 1 | | | | | | | | |
| SDQ-Prosocial behavior (5) | **-0.1** (14495) | **-0.39** (14498) | **-0.27** (14494) | **-0.24** (14494) | 1 | | | | | | | |
| SDQ-Total (6) | **0.7** (14477) | **0.71** (14477) | **0.78** (14477) | **0.64** (14477) | **-0.35** (14476) | 1 | | | | | | |
| Physical activity (7) | **-0.09** (13963) | -0.02+ (13970) | -0.00 (13965) | **-0.15** (13962) | **0.05** (13986) | **-0.09** (13949) | 1 | | | | | |
| Socioeconomic status (8) | **-0.13** (14347) | **-0.16** (14353) | **-0.22** (14351) | **-0.17** (14347) | **0.06** (14375) | **-0.24** (14330) | **0.12** (16382) | 1 | | | | |
| Body-mass index (9) | 0.02+ (14416) | 0.02+ (14421) | **-0.06** (14418) | **0.13** (14416) | 0.00 (14448) | 0.03* (14397) | **-0.12** (16520) | **-0.08** (17168) | 1 | | | |
| **Wave 1** | | | | | | | | | | | | |
| Emotion (10) | **0.38** (6465) | **0.17** (6466) | **0.19** (6465) | **0.19** (6465) | **-0.05** (6469) | **0.33** (6462) | **-0.07** (7969) | **-0.11** (8395) | 0.01 (8367) | 1 | | |
| SDQ-Behavioral Problems (11) | **0.16** (6464) | **0.43** (6465) | **0.31** (6464) | **0.2** (6464) | **-0.22** (6468) | **0.39** (6461) | **-0.04** (7970) | **-0.13** (8396) | 0.03* (8368) | **0.28** (8440) | 1 | |
| SDQ-Hyperactivity inattention (12) | **0.15** (6465) | **0.33** (6466) | **0.54** (6465) | **0.19** (6465) | **-0.18** (6469) | **0.45** (6462) | **-0.06** (7968) | **-0.17** (8395) | **-0.07** (8366) | **0.28** (8439) | **0.46** (8439) | 1 |
| SDQ-Peer problems (13) | **0.2** (6462) | **0.22** (6463) | **0.23** (6462) | **0.4** (6462) | **-0.16** (6466) | **0.36** (6459) | **-0.11** (7967) | **-0.14** (8393) | **0.07** (8365) | **0.34** (8438) | **0.29** (8439) | **0.25** (8437) |
| SDQ-Prosocial Behavior (14) | **-0.09** (6463) | **-0.23** (6464) | **-0.17** (6463) | **-0.17** (6463) | **0.38** (6467) | **-0.23** (6460) | 0.02+ (7968) | 0.03* (8394) | -0.01 (8366) | **-0.11** (8439) | **-0.37** (8439) | **-0.24** (8438) |
| SDQ-Total (15) | **0.32** (6462) | **0.4** (6463) | **0.47** (6462) | **0.33** (6462) | **-0.21** (6466) | **0.55** (6459) | **-0.1** (7964) | **-0.2** (8391) | 0.00 (8362) | **0.69** (8436) | **0.70** (8436) | **0.76** (8436) |
| Physical activity (16) | **-0.08** | 0.01 | 0.03+ | **-0.07** | -0.01 | -0.03+ | **0.04** | **0.04** | **-0.04** | **-0.10** | 0.02+ | **0.04** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (6183) | (6183) | (6182) | (6183) | (6186) | (6180) | (7689) | (8106) | (8080) | (8096) | (8096) | (8094) |
| Body-mass index (17) | **0.07** (5457) | **0.04** (5458) | **0.08** (5457) | **0.12** (5457) | 0.04* (5461) | **0.11** (5454) | **0.07** (6830) | **-0.14** (7196) | **0.63** (7166) | **0.05** (7226) | **0.05** (7227) | -0.03+ (7225) |
| **Wave 2** | | | | | | | | | | | | |
| SDQ-Emotion (18) | **0.23** (2598) | **0.14** (2598) | **0.12** (2597) | **0.15** (2598) | **-0.06** (2601) | **0.23** (2597) | **-0.08** (4212) | **-0.12** (4474) | 0.03+ (4453) | **0.42** (3861) | **0.17** (3861) | **0.17** (3860) |
| SDQ-Behavioral problems (19) | **0.09** (2601) | **0.28** (2601) | **0.24** (2600) | **0.14** (2601) | **-0.18** (2604) | **0.29** (2600) | -0.05* (4215) | **-0.11** (4478) | 0.04* (4456) | **0.13** (3865) | **0.44** (3865) | **0.33** (3864) |
| SDQ-Hyperactivity inattention (20) | 0.04 (2602) | **0.25** (2602) | **0.37** (2601) | **0.14** (2602) | **-0.18** (2605) | **0.33** (2601) | **-0.07** (4214) | **-0.16** (4477) | 0.03+ (4455) | **0.17** (3864) | **0.31** (3864) | **0.59** (3863) |
| SDQ-Peer problems (21) | **0.1** (2596) | **0.12** (2596) | **0.17** (2595) | **0.28** (2596) | **-0.13** (2599) | **0.25** (2595) | **-0.07** (4212) | **-0.11** (4474) | **0.05** (4451) | **0.19** (3860) | **0.21** (3860) | **0.21** (3859) |
| SDQ-Prosocial behavior (22) | -0.05+ (2599) | **-0.16** (2599) | **-0.14** (2598) | **-0.14** (2599) | **0.32** (2602) | **-0.18** (2598) | 0.04+ (4213) | 0.01 (4475) | 0.02 (4452) | **-0.05** (3863) | **-0.26** (3863) | **-0.17** (3862) |
| SDQ-Total (23) | **0.16** (2595) | **0.28** (2595) | **0.33** (2594) | **0.25** (2595) | **-0.19** (2598) | **0.39** (2594) | **-0.09** (4209) | **-0.18** (4469) | **0.06** (4447) | **0.33** (3858) | **0.39** (3858) | **0.48** (3857) |
| Physical activity (24) | -0.04+ (2525) | 0.01 (2525) | -0.01 (2524) | -0.03 (2525) | -0.02 (2528) | -0.04 (2524) | 0.04* (4076) | 0.03+ (4338) | 0.03 (4315) | **-0.07** (3774) | 0.01 (3774) | 0.01 (3773) |
| Body-mass index (25) | 0.02 (4913) | **0.05** (4915) | **0.07** (4914) | **0.12** (4916) | 0.01 (4920) | **0.09** (4913) | -0.00 (6092) | **-0.15** (6384) | **0.61** (6384) | 0.04* (4552) | **0.05** (4551) | 0.02 (4551) |

Table 1A. continue

| | (13) | (14) | (15) | (16) | (17) | (18) | (19) | (20) | (21) | (22) | (23) | (24) | (25) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wave 1** | | | | | | | | | | | | | |
| SDQ-Peer problems (13) | 1 | | | | | | | | | | | | |
| SDQ-Prosocial Behavior (14) | **-0.23** (8437) | 1 | | | | | | | | | | | |
| SDQ-Total (15) | **0.63** (8436) | **-0.33** (8434) | 1 | | | | | | | | | | |
| Physical activity (16) | **-0.09** (8093) | 0.01 (8094) | **-0.04** (8091) | 1 | | | | | | | | | |
| Body-max index (17) | **0.14** (7225) | -0.03+ (7226) | **0.06** (7222) | **-0.18** (6948) | 1 | | | | | | | | |
| **Wave 2** | | | | | | | | | | | | | |
| SDQ-Emotion (18) | **0.17** (3861) | -0.04+ (3861) | **0.34** (3860) | **-0.07** (3800) | 0.04+ (3436) | 1 | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SDQ-Behavioral problems (19) | **0.18** (3865) | **-0.24** (3865) | **0.39** (3864) | 0.01 (3804) | 0.04+ (3439) | **0.28** (4507) | 1 | | | | | | |
| SDQ-Hyperactivity inattention (20) | **0.17** (3864) | **-0.15** (3864) | **0.48** (3863) | 0.05***** (3803) | -0.03 (3439) | **0.29** (4506) | **0.5** (4509) | 1 | | | | | |
| SDQ-Peer problems (21) | 0.45 (3860) | **-0.16** (3860) | **0.36** (3859) | **-0.1** (3799) | **0.09** (3434) | **0.37** (4504) | **0.27** (4506) | **0.24** (4504) | 1 | | | | |
| SDQ-Prosocial behavior (22) | **-0.15** (3863) | **0.45** (3863) | **-0.22** (3862) | 0.01 (3802) | 0.00 (3438) | **-0.1** (4506) | **-0.44** (4507) | **-0.27** (4506) | **-0.24** (4504) | 1 | | | |
| SDQ-Total (23) | **0.34** (3858) | **-0.2** (3858) | **0.56** (3857) | -0.03 (3797) | 0.04+ (3433) | **0.7** (4502) | **0.7** (4502) | **0.76** (4502) | **0.65** (4502) | **-0.36** (4502) | 1 | | |
| Physical activity (24) | **-0.06** (3774) | -0.02 (3774) | -0.04+ (3773) | **0.19** (3715) | **-0.1** (3359) | **-0.12** (4315) | 0.01 (4319) | 0.05***** (4318) | **-0.11** (4314) | 0.00 (4315) | **-0.07** (4309) | 1 | |
| Body-mass index (25) | **0.13** (4551) | 0.00 (4552) | **0.08** (4550) | **-0.14** (4458) | **0.74** (3954) | 0.04+ (3519) | **0.06** (3523) | -0.02 (3522) | **0.11** (3518) | 0.01 (3519) | **0.06** (3513) | **-0.11** (3502) | 1 |

Bold numbers: $p<.001$, *$p<.01$, +$p<.05$

## 3.3 Original Article 3

Ganjeh, P., Hagmayer, Y., Meyer, T., Kuhnert, R., Ravens-Sieberer, U., von Steinbuechel, N., Rothenberger, A., and Becker, A. (submitted). Physical activity and psychopathology: Are long-term developmental trajectories of physical activity in youngsters associated with trajectories of general mental health problems and of attention-deficit hyperactivity (ADHD) symptoms?

# Physical activity and psychopathology: Are long-term developmental trajectories of physical activity in youngsters associated with trajectories of general mental health problems and of attention-deficit hyperactivity (ADHD) symptoms?

**Parisa Ganjeh [1, *], York Hagmayer [2], Thomas Meyer [3], Ronny Kuhnert [4], Ulrike Ravens-Sieberer [5], Nicole von Steinbuechel [6], Aribert Rothenberger [1, †] and Andreas Becker [1, †]**

[1] Department of Child and Adolescent Psychiatry and Psychotherapy, University Medical Center Göttingen, Göttingen, Germany; arothen@gwdg.de (A.R.); abecker4@gwdg.de (A.B.)

[2] Department of Cognitive Science and Decision Psychology, Georg-Elias-Müller-Institute for Psychology, University of Göttingen, Göttingen, Germany; york.hagmayer@bio.uni-goettingen.de

[3] Department of Psychosomatic Medicine and Psychotherapy, University Medical Center Göttingen, Göttingen, Germany; thomas.meyer@med.uni-goettingen.de

[4] Unit Mental Health, Department of Epidemiology and Health Monitoring, Robert Koch Institute, Berlin, Germany; kuhnertr@rki.de

[5] Department of Child and Adolescent Psychiatry, Psychotherapy and Psychosomatics, University Medical Center Hamburg-Eppendorf, Hamburg, Germany; ravens-sieberer@uke.uni-hamburg.de

[6] Institute of Medical Psychology and Medical Sociology, University Medical Center Göttingen, Göttingen, Germany; nvsteinbuechel@med.uni-goettingen.de

*** Correspondence:**
Parisa Ganjeh
parisa.ganjeh@med.uni-goettingen.de

†These authors share senior authorship.

**Keywords: Physical activity, general mental health problems, ADHD, developmental trajectories, children, adolescents**

## Abstract:

A medium-to-high level of physical activity (PA) may have at least a short-term positive effect on psychopathology in children and adolescents. Hence, the objective of this study was to investigate the long-term effects of PA in youngsters on their general mental health problems and/or ADHD symptoms, using trajectories of concurrent development over a period of about 10 years. This study employed data from the German Health Interview and Examination Survey for Children and

Adolescents (KiGGS) collected at three time points (Baseline, Wave 1, Wave 2, over 10 years) from 17,640 children and adolescents. Using parent-reported data from the Strengths and Difficulties Questionnaire (SDQ), different developmental trajectories of general mental health problems (SDQ-total) and ADHD symptoms (SDQ-H/I) were identified with latent class mixed models (LCMM) statistics. This was also applied to parent- and self-reported data of three levels of PA. The latter was assessed according to WHO recommendations. The joint probability of class membership for SDQ-total as well as ADHD symptoms with PA was calculated to generate the concurrent developmental trajectories between variables. Results showed a 4-class trajectory model for both SDQ-total and ADHD symptoms among boys and girls. The majority of children and adolescents showed “low general difficulties” and “low ADHD symptoms” over the period of ten years. Three distinct trajectories in boys and four distinct trajectories in girls were found for PA. Most of the participants showed an “increasing-decreasing activity” trajectory. No statistically significant correlations were found between the different SDQ-total or ADHD symptom trajectories and the trajectories of PA in the two genders. Taken together, our findings did not indicate any significant relationship between waxing and waning PA course over ten years and various classes of mental health problems for children and adolescents. In contrast to our cross-sectional findings, no steady long-term medium/high-level of PA was present, which could (at least partly) explain the non-significant findings.

**Introduction**

Most mental health problems begin in childhood or adolescence, and 10-20% of children and adolescents are thought to have such a disorder [1]. Various psychosocial and cognitive maladjustments may occur before adulthood, when symptoms first appear [2]. Therefore, not only approaches for early detection but also for early prevention and low-level support are needed. In recent years, it has been shown that, according to WHO recommendations, high levels of weekly physical activity (PA) may be a helpful way to improve mental health problems in children and adolescents, at least in the short-term [3-13]. Since mental health problems in children and adolescents are often of long-term duration, the question arises as to whether PA can also be beneficial in these cases. Looking at concurrent long-term developmental trajectories of PA and mental health problems may be helpful in finding an answer. Considering that physical inactivity is a behavioral risk factor for mental illness [14], children and adolescents with consistently moderate-to-high levels of PA should be more protected in the long run. This may be especially relevant during the sensitive age period of growth and development which we are investigating.

Our epidemiological approach using data from a general adolescent population will clarify whether PA may be relevant in the context of the developmental course of psychopathology.

The developmental trajectories of mental health symptoms differ widely among populations [15], and a large body of research has identified developmental variations in mental health issues [16–22]. Although children's developmental trajectories are reliable across different forms of mental health problems [17], some researchers have highlighted categories of children with increasing or decreasing symptoms [18]. For example, Augustine et al. reported that, independent of neurodevelopmental disorders in adolescents (n=949), emotional and psychosomatic problems in girls worsens with time [23]. By means of growth-mixture modeling techniques, researchers have discovered different developmental trajectories of mental health problems in children and adolescents. Using the Strengths and Difficulties questionnaire (SDQ) subscale Emotional Symptoms, four trajectories of depressive symptoms were observed in a sample of 4,983 Australian children: low-stable (75%), decreasing (11%), increasing (9%), and high and increasing (6%) groups [24]. Furthermore, in another large population of children aged 3 to 17 (n=10,648), four different trajectories of conduct problems were reported: early-onset persistent, adolescence-onset, childhood-limited, and low level [25]. Children aged 4 to 12 (n=3,717) were divided into six groups based on their overall mental health risk trajectory (total difficulty score of the SDQ questionnaire): low difficulties (73%), improvers (10%), decliners (8%), early decliners/late improvers (5%), late decliners/early improvers (3%), and high difficulties (2%) [17].

In a representative epidemiological sample of 564 children living in Germany from the BELLA study, a sub-study of KiGGS, latent class growth analysis revealed the presence of three distinct trajectories of the SDQ dysregulation profile in children aged 9 to 13 years in boys and girls: low SDQ-DP (girls 67% and boys 60%), moderate SDQ-DP (girls 28% and boys 32%), and high SDQ-DP (girls 5% and boys 9%) [26]. The moderate and low SDQ-DP subgroups courses remained stable over 2 years, whereas, in the high SDQ-DP subgroup, boys showed a decreasing and girls an increasing trend in symptom severity. Shore et al. demonstrated in a systematic review and meta-analysis of 20 studies that 26% of the study subjects (n=41,236) were on a "moderate" trajectory and 56% were on a trajectory with "no or low" depressive symptoms [27]. For 12% of the sample, there were distinct "high," "increasing," and "decreasing" depressive symptom subgroups. However, only six of the twenty studies included data collected before the age of twelve [27]. Using data from the UK Millennium Cohort Study (n=15,439) assessing emotional and

behavioral symptoms at ages of 3, 5, 7, and 11 years, latent class analysis revealed five groups: low symptoms (57%), moderate behavioral (21%), moderate emotional (13%), high emotional-moderate behavioral (6%), and high behavioral-moderate emotional (4%) [28]. However, the diversity of trajectories of mental health problems in children and adolescents makes it difficult to predict the long-term outcomes of these young study participants. Therefore, looking at long-term, concurrent trajectories may provide more insight into the development of symptoms in childhood.

To date, cross-sectional and longitudinal follow-up studies have demonstrated that PA may have a positive impact on general mental health problems and ADHD symptoms [29, 30], although previous studies have indicated that there is considerable heterogeneity in the developmental course of ADHD symptoms [31–38]. For example, a longitudinal cohort study in children aged 7 to 15 years (n=1,620) examined the trajectories of ADHD in terms of externalizing and internalizing symptoms and identified six different groups [15]. Likewise, six developmental trajectory groups of ADHD symptoms (SDQ subscale) were identified using data from the UK Millennium Cohort study including n=11,316 children aged 3 to 14 years [39]. In contrast, Brinksma et al. described four ADHD symptom trajectories in adolescents aged 10 to 18 years (n=1,730): low (59%), moderate stable (19%), high decreasing (11%), and high persistent (11%) [40]. Three ADHD symptom trajectories (low, moderate, high) were identified in the Québec Longitudinal Study of Child Development in children from 5 months to 17 years of age (n=1,407) [41]. Furthermore, in 1,571 children and adolescents (7 to 15 years old) the growth mixture model for hyperactivity/impulsivity found three classes, different for boys and girls [42]. This heterogeneity of study results presents a challenge for describing practically useful and reproducible developmental trajectories for ADHD symptoms.

Some studies have reported different developmental trajectories for PA [43–45]. Yang et al. found three types of moderate-to-vigorous PA in adolescent girls aged 14 to 23 years (n=556 at age 14) [46]. In data from two Canadian longitudinal studies, Riglea et al. confirmed a wide variability of moderate-to-vigorous PA trajectories [47]. Aira et al. observed five PA trajectories in adolescents aged 15 to 19 years (n=254) [48]. Using parent-reported data from the Australian Raine study (n = 1,628), three trajectories of low (13%), moderate (65%) and high PA (22%) were identified in children and adolescents aged 8 to 17 years [49]. Likewise, in the British population-based Avon Longitudinal Study of Parents and Children cohort, three distinct PA trajectories were identified in children aged 11 to 15 years (n=3,584) [50]. According to a recent systematic review

of distinct trajectories of PA, three or four different trajectory classes were most frequently found among the reviewed studies, and several of the trajectories described a decline in PA during later childhood and adolescence [51].

There is limited evidence on the concurrent trajectories of PA in daily life that may influence mental health. More information could help to better understand these heterogeneous trajectories in the context of daily life challenges. In the present study, we examined the trajectories of general mental health problems, ADHD symptoms, and PA over a period of more than 10 years in a large representative sample. We investigated whether there were different classes of trajectories and examined how the resulting trajectories of mental health problems and PA related to each other.

## Methods

### Participants and procedures

The longitudinal and large German Health Interview and Examination Survey for Children and Adolescents (KiGGS), which was carried out by the Robert Koch Institute, Berlin, served as the data source for this study. In other reports [52–54], the goal and design of the KiGGS study have been described in detail. Data were collected in three waves covering the periods from 2003 to 2006 (Baseline), 2009 to 2012 (Wave 1), and 2014 to 2017 (Wave 2). In total, 8,656 girls and 8,985 boys between the ages of 0 and 17 participated at Baseline along with their parents. At 167 study locations dispersed throughout Germany, participants were chosen at random using a stratified sampling technique. For boys and girls, the response rates were 66% and 67%, respectively. After a lapse of roughly 6 years, the first follow-up survey (Wave 1) was conducted using a telephone questionnaire. To this end, 11,992 (68%) of the Baseline participants were again invited and took part in the examination for this wave [55]. In Wave 2, a cross-sectional and longitudinal sample of 15,023 children and adolescents aged between 0 and 17 years was used. There were 10,853 girls and boys with a response rate of 61.5% in the Wave 2 longitudinal sample [56, 57].

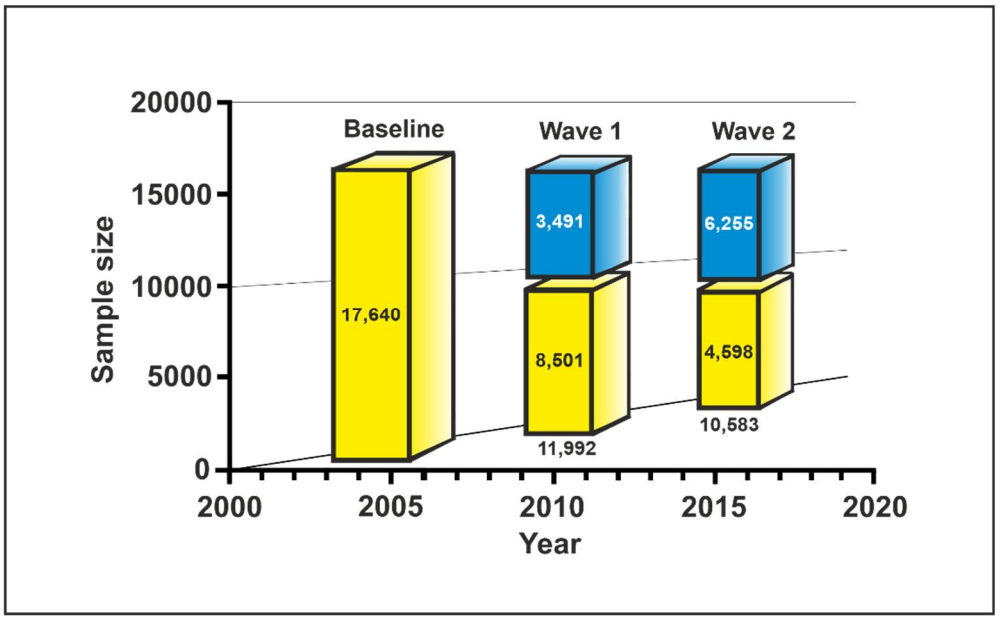


Figure1. Longitudinal sample sizes of the KiGGS study. Yellow bars: Longitudinal data up to 17 years old (the data used for analyses in the current study). Blue bars: Longitudinal data at Wave 1 and Wave 2 older than 17 years

## Measurements

### Physical activity (PA)

At Baseline, PA was a composite variable created from a number of inquiries about the frequency with which children and adolescents participated in various sports and other physical activities. For children and adolescents aged 0 to 10 years, their parents or guardians provided data for PA. From the responses, three ordered categories of PA were calculated: 1 for low, 2 for medium, and 3 for high. For the assessments in Waves 1 and 2, the WHO's recommendations for PA were taken into consideration [58]. The question "How many days is your child/are you at least 60 minutes physically active during a typical week?" was posed to both parents and adolescents. Respondents had seven options: from 0 for never to 7 for every weekday. Three categories of PA were also defined for the responses at Waves 1 and 2, namely: low = never to 2 days per week, medium = 3 to 5 days per week, and high = 6 to 7 days per week, to enable a comparison between time points. Consequently, PA was an ordered categorical variable with three levels for each of the three time points (low, medium, and high). The study protocol stated that because PA was evaluated by both parents (for children aged 0 to 10) and teenagers, it is a mixed-report variable. This choice was made since adolescents may more reliably provide behavioral information about themselves than younger children, due to their more developed memory and self-perception processes. Additionally, studies have shown that there is little agreement between parents' and adolescents' reports of PA [59–61], and that the agreements that do exist are typically related to organized PA [62]. Thus, the use of mixed reports of PA in this study was justified.

**Mental health problems and ADHD symptoms**

The Strength and Difficulties Questionnaire (SDQ) was used to assess mental health [63]. The SDQ consists of 25 items that ask respondents to rate statements on a scale from 0 (not true) to 2 (certainly true). The SDQ has five subscales: prosocial behavior, peer problems, hyperactivity/inattention, conduct problems, and emotional problems. These sub-scales have scores that range from 0 to 10. With the exception of the prosocial behavior scale, the total difficulties score is calculated by combining the scores of the subscales. A higher score represents more difficult levels. In the current analysis, the total difficulties score and the hyperactivity/inattention score (SDQ-H/I) were used as indicators for general mental health problems and ADHD symptoms, respectively, and were taken from the parent-rated reports. The psychometric properties of the SDQ were examined in normal [64] and clinical [65] samples of German children and adolescents. It was demonstrated that the questionnaire is a reliable tool for identifying psychiatric patients [64, 65]. The SDQ-H/I sub-scale and the overall SDQ score in this study had Cronbach's alphas of 0.80 and 0.76, respectively. It is also interesting to note that the scores of the Child Behavior Checklist [64] and the outcome scores of the SDQ have a significant correlation.

**Statistics**

Descriptive statistics were conducted by IBM SPSS Statistics for Windows, Version 26.0 (International Business Machines Corporation, New York, USA). To identify different developmental trajectories, we carried out latent class mixed models (LCMM), using the R package lcmm [66]. First, we used latent class mixed models to group children into different classes of trajectories according to their development of general mental health problems (SDQ-total), ADHD symptoms (SDQ-H/I), and PA from Baseline to Wave 2. In our models, shapes of trajectories were polynomial including a linear and quadratic trend over time. No random effects were included in the models. Models including one (basic) to five classes of trajectories were computed and compared. The Bayesian information criterion (BIC), the Akaike information criterion (AIC), entropy, and class size were used for comparisons [67]. The model with the lowest BIC and AIC and higher entropy values is the one that fits the data the best. We chose the model based on whether classes included a substantial number of participants and whether classes were of conceptual significance, i.e., showed clearly distinct trajectories that captured different developments over time. In order to investigate the relationship among trajectories of PA and mental health problems (SDQ-total) as well as trajectories of PA and symptoms of ADHD, we used crosstabs and

calculated Cramer's v as a measure of association and tested it for significance. Cramer's v has ranges between 0 and +1, and there is no association when the value is close to 0. A Cramer's v value greater than 0.25 is defined as a very strong relationship.

## RESULTS

### Sample

The total sample at Baseline was 17,640 children and adolescents (8,654 girls and 8,986 boys) aged 0 to 17 years. We used data for children and adolescents up to 17 years old, because parent-reported SDQ data were only available up to this age. The exact numbers and descriptive characteristics of the longitudinal sample at Baseline, Wave 1, and Wave 2 are shown in Table 1. Note that the number of participants declines across the three waves due to participants' dropping out.

Table 1. Descriptive characteristics of the study population at Baseline, Wave 1, and Wave 2

| | | Baseline | | | | Wave 1 | | | | Wave 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Boys (n=8,986) | | Girls (n=8,654) | | Boys (n=4,274) | | Girls (n=4,274) | | Boys (n=2,258) | | Girls (n=2,340) | |
| | | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Age (years) | | 8.54 | 5.053 | 8.48 | 5.09 | 11.77 | 3.37 | 11.70 | 3.39 | 14.01 | 1.99 | 13.98 | 1.98 |
| SDQ-Emotion | | 1.69 | 1.79 | 1.87 | 1.80 | 1.75 | 1.75 | 2.15 | 1.91 | 1.45 | 1.73 | 1.94 | 1.94 |
| SDQ-Behavioral problems | | 2.09 | 1.60 | 1.78 | 1.44 | 2.09 | 1.58 | 1.79 | 1.44 | 1.69 | 1.50 | 1.39 | 1.33 |
| SDQ-Hyperactivity inattention | | 3.54 | 2.34 | 2.72 | 2.31 | 3.32 | 2.25 | 2.55 | 2.05 | 2.99 | 2.15 | 2.17 | 1.89 |
| SDQ-Peer problems | | 1.56 | 1.68 | 1.32 | 1.53 | 1.42 | 1.57 | 1.17 | 1.40 | 1.50 | 1.73 | 1.15 | 1.43 |
| SDQ-Prosocial behavior | | 7.55 | 1.77 | 8.06 | 1.62 | 8.08 | 1.62 | 8.62 | 1.41 | 7.71 | 1.82 | 8.29 | 1.59 |
| SDQ-total | | 8.88 | 5.34 | 7.69 | 4.86 | 8.58 | 5.09 | 7.66 | 4.78 | 7.63 | 5.06 | 6.65 | 4.69 |
| Physical activity | Low | 2668 | | 3337 | | 646 | | 1048 | | 440 | | 774 | |
| | Medium | 2833 | | 2589 | | 2090 | | 2015 | | 1081 | | 1092 | |
| | High | 2992 | | 2229 | | 1340 | | 1011 | | 607 | | 373 | |
| | Total | 8493 | | 8155 | | 4076 | | 4074 | | 2128 | | 2239 | |

### Latent trajectories of general mental health problems and ADHD symptoms

Unconditional latent class mixed models (LCMM) with 1 to 5 latent trajectory classes were estimated separately for general mental health problems (SDQ-total) and ADHD symptoms in boys and girls. For more details on the fit indices of the models and group sizes of classes, see Appendix A (Tables A1-A4).

After comparing the different models, the 4-class model was chosen for SDQ-total and ADHD symptoms in both boys and girls. This model type includes a specific group with increasing trajectories in SDQ-total and ADHD symptoms for boys and girls (i.e. mental health problems

increased over time, see Figures 2 and 3). We did not choose the five-class model, since it only had a slightly better fit than the four-class model, but groups sizes of classes decreased and some of the models had lower entropy than the corresponding four-class models. Figures 3 and 4 show the classes of trajectories identified by the four-class models for both genders.

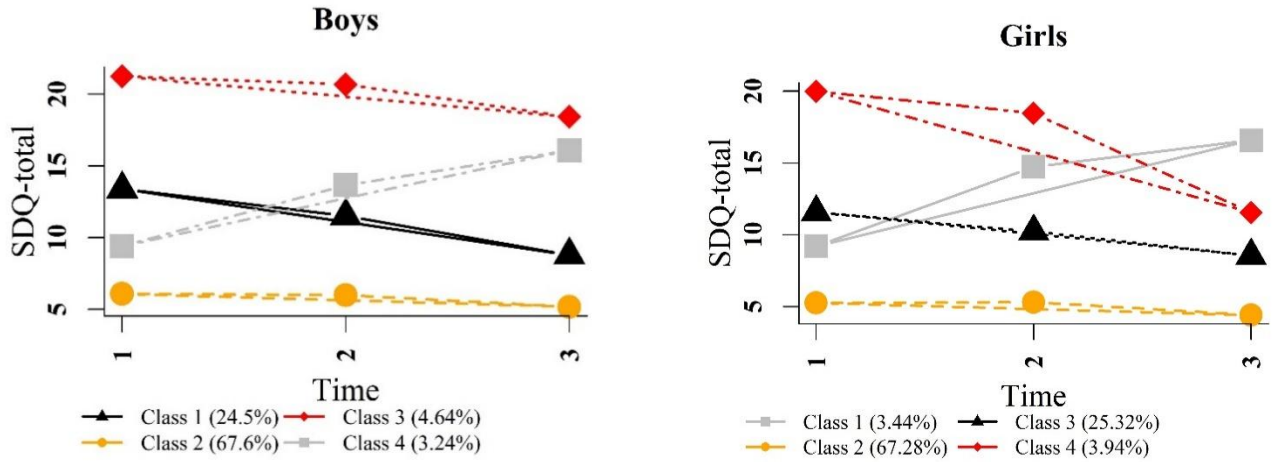


Figure 2. SDQ-total trajectories for boys and girls in four-class models

For the SDQ-total score, the largest class (depicted in yellow in Figure 2) included 67.6% of boys and 67.3% of girls and was labeled as “low difficulties”, indicating that these class members had low mental health problems at every time point. The second biggest class (depicted in black in Figure 2) labeled as “medium difficulties” had a decreasing trend and encompassed 24.5% of boys and 25.3% of girls, respectively. The third class started with a high initial score of SDQ-total, which decreased over time (depicted in red in Figure 2), and was therefore labeled "high difficulties". It included 4.6% and 3.9% of boys and girls. The smallest class (depicted in gray in Figure 2) showed an increasing trend and was therefore named “increasing difficulties”. It included 3.2% of boys and 3.4% girls.

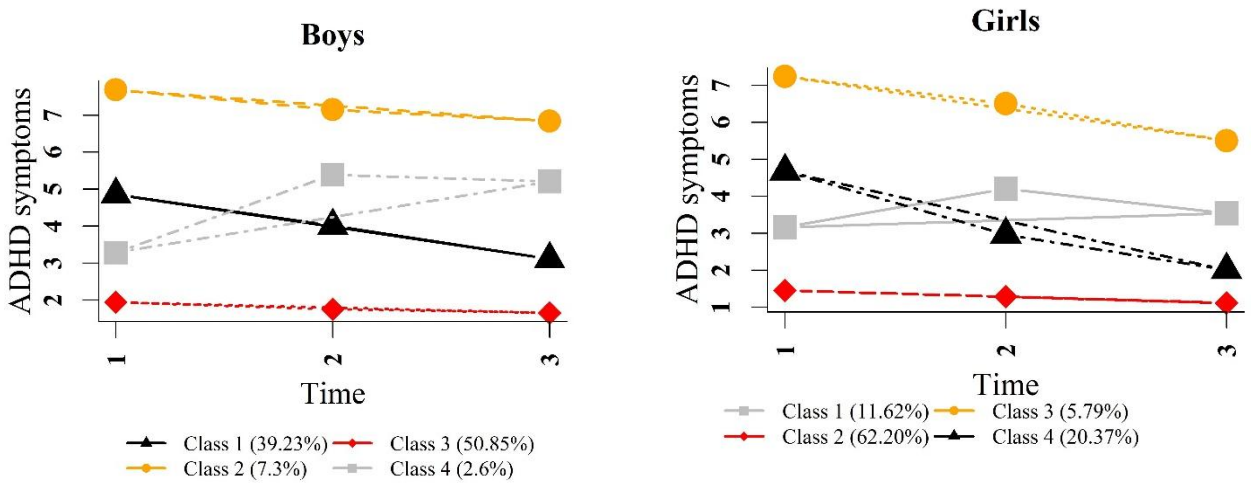


Figure 3. ADHD symptom trajectories for boys and girls in the four-class models

Four distinct classes of trajectories were identified for ADHD symptoms. The majority of boys (50.85%) and girls (62.2%) were in the class entitled "low symptoms" (depicted in red in Figure 3). All members of this class had no or low ADHD symptoms at all three time points. The second largest class (depicted in black in Figure 3) included 39.23% of boys and 20.37% of girls and started with medium scores of ADHD with a decreasing trend labeled "medium symptoms". The class named “high symptoms” (depicted in yellow in Figure 3) included 7.3% of boys and with 5.8% the lowest percentage of girls. Children and adolescents in this class began with high ADHD symptoms at baseline and showed a decreasing trend to Wave 2. Finally, the class labeled “increasing symptoms” (depicted in gray in Figure 3) encompassed 11.62% of girls and the lowest percentage of boys (2.6%). ADHD symptoms in this class increased from baseline to Wave 1 and then decreased slightly to Wave 2 for girls, whereas they remained relatively stable for boys.

**Latent trajectories of PA**

In order to determine the number of trajectory classes for PA, the literature was reviewed. Three or four classes of trajectories were most frequently reported for children and adolescents according to a systematic review of various trajectories of PA by Lounassalo et al [51]. Therefore, we only fitted models with three and four classes to the data for PA (for more details see Appendix B, Tables and Figures B1-B2). For boys, the 3-class approach was selected due to very few members in the fourth class (less than 1%). Class number 1 was named “increasing activity” with very few participants (1.4%). The second class included most boys (58.3%) and was named “increasing and decreasing activity”. In this class, PA increased from baseline to Wave 1, but decreased after that. Class number 3, named “decreasing activity”, included 40.3% of boys. The trajectory of PA decreased in this class. Table 2 shows the development of the level of PA at the three time points for all classes.

Table 2. Distribution of PA levels at three time points for the three classes of trajectories identified in boys

| | Baseline (Time 1) | | | Wave 1 (Time 2) | | | Wave 2 (Time 3) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| Class 1 (increasing activity) | 100% | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 100% |
| Class 2 (increasing and decreasing activity) | 52% | 46% | 0.0% | 24% | 61% | 15% | 33% | 60% | 7% |
| Class 3 (decreasing activity) | 0% | 13% | 87% | 8% | 44% | 47% | 14% | 49% | 37% |

For girls, a 4-class model was chosen, because the model with three classes did not converge. The first class contained girls (1.4%), who began their PA at low and medium levels and subsequently decreased their activity. The label given to this class type was "low and decreasing activity". Class number 2, which included the highest percentage of girls (71.5%), was named “increasing and decreasing activity”. The third class included the lowest number of girls (0.7%) and was labeled as “increasing activity”. Class number 4 was named “high and decreasing activity”. This class included 26.5% of girls who displayed a decreasing trend in PA starting from a high level. The development of the PA levels at the three time points for the four classes are depicted in Table 3.

Table 3. Distribution of levels of PA at three time points for the four classes of trajectories identified in girls

| | Baseline (Time 1) | | | Wave 1 (Time 2) | | | Wave 2 (Time 3) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| Class 1 (low and decreasing activity) | 47% | 53% | 0% | 100% | 0% | 0% | 100% | 0% | 0% |
| Class 2 (increasing and decreasing activity) | 55% | 45% | 0% | 24% | 54% | 22% | 33% | 55% | 13% |
| Class 3 (increasing activity) | 100% | 0% | 0% | 0% | 0% | 100% | 0% | 0% | 100% |
| Class 4 (high and decreasing activity) | 0% | 0% | 100% | 25% | 50% | 26% | 31% | 50% | 18% |

**Relationship of classes of trajectories of general mental health problems (SDQ-total) and PA**

The relationship between trajectories of SDQ-total and PA is depicted in Figure 4 for boys and in Figure 5 for girls. These figures show that the distribution of classes of PA was very similar for the different classes of SDQ-total for boys and girls. This indicated no relation among classes of PA and SDQ trajectories. The statistical analysis found only small, non-significant associations between classes of SDQ-total and PA trajectories for boys ($c^2$ (6) = 0.10219, p = 1; Cramer’s v = 0.113) and girls ($c^2$((9) = 0.04319, p =1; Cramer’s v = 0.06).

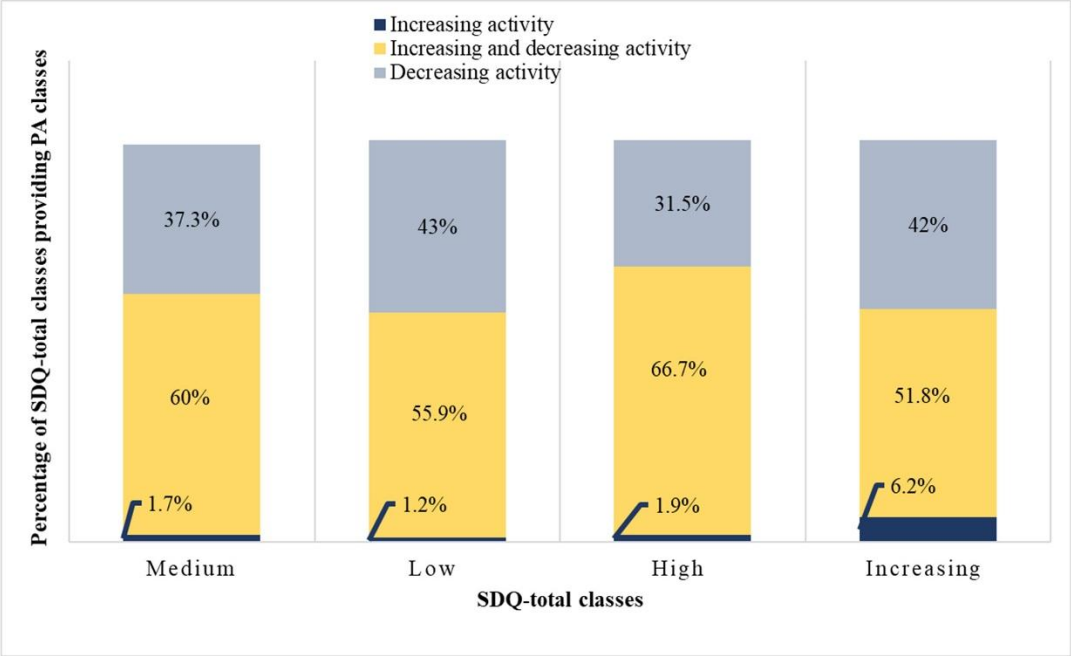


Figure 4. Association between SDQ-total and PA classes in boys $c^2(6) = 0.10219$, p =1; Cramer's v = 0.113

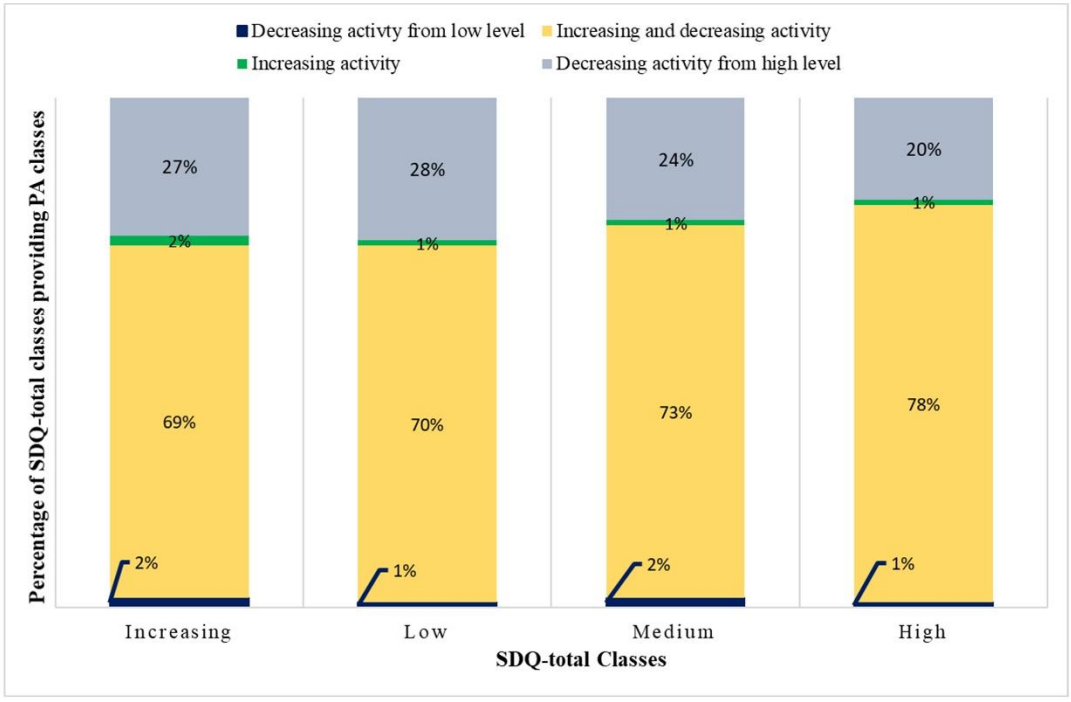


Figure 5. Association between SDQ-total and PA classes in girls $c^2(9) = 0.04319$, p =1; Cramer's v = 0.06

**Relationship of classes of trajectories of ADHD symptoms and PA**

We used the same graphs to depict the relationship of classes of trajectories of ADHD symptoms and classes of trajectories of PA. Figure 6 shows the results for boys and Figure 7 for girls. Again, the distribution of classes of PA across the classes of ADHD symptoms looked rather similar, indicating no relation. The classes of trajectories were not significantly associated for boys ($c^2$ (6) = 0.04781, p = 1; Cramer's v = 0.077) and girls ($c^2$ (9) = 0.0511, p = 1; Cramer's v = 0.065).

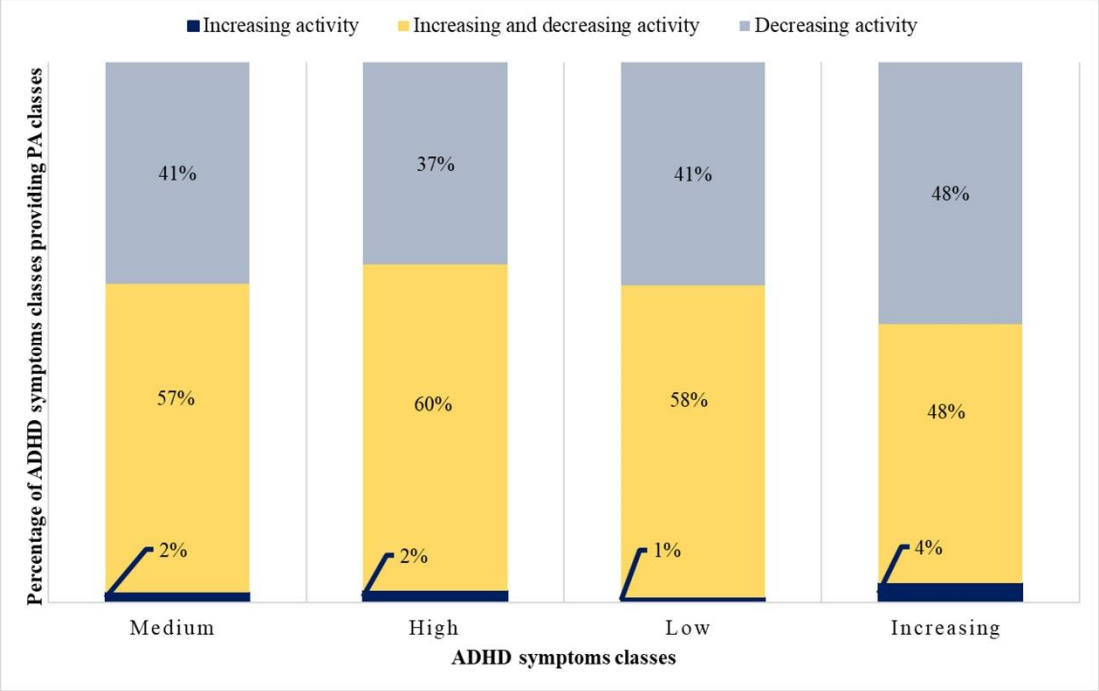


Figure 6. Association between ADHD symptoms and PA classes in boys ($c^2$ (6) = 0.04781, p = 1; Cramer's v = 0.077)

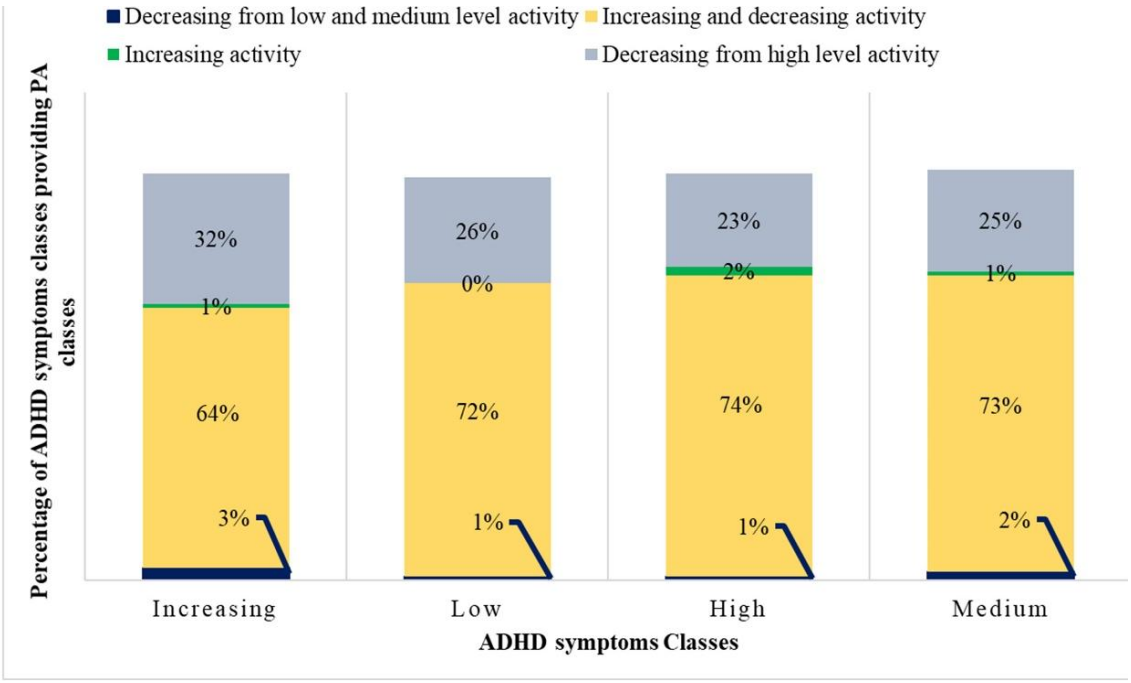


Figure 7. Association of ADHD symptoms and PA classes for girls ($c^2$ (9) = 0.0511, p = 1; Cramer's v = 0.065

## Discussion

Growing evidence shows that there is heterogeneity with respect to developmental courses of general mental health problems and specific psychopathological problems including ADHD symptoms in children and adolescents [15, 17, 24, 25, 39, 40]. In addition, there is some indication of an overall positive effect of PA on mental health problems in children and adolescence [5–7, 9–11]. However, it remains unclear whether this is also the case when comparing different long-term developmental trajectories of psychological problems from childhood to late adolescence. The present study investigates the effects of PA trajectories on the development of general mental health problems and ADHD symptoms in a cohort of German adolescents. Here we identified four different trajectories of general mental health problems and ADHD symptoms as well as a 3-class trajectory approximation for PA in male study participants and a 4-class model in female participants. However, no significant associations were found among optimal classes between PA and either general mental problems or ADHD symptoms classes.

The results from our analysis revealed that models with four different classes for trajectories of general mental health problems (SDQ-total) as well as ADHD symptoms fit best for the data. The classes for boys and girls in relation to the SDQ total score were labeled as "low difficulties", "medium difficulties", "high difficulties", and "increasing difficulties". These findings were consistent with previous work which showed developmental heterogeneity in different kinds of

mental health problems for children and adolescents [18, 19, 27, 28]. They are also in line with studies that grouped most of their population into low mental health problems [24, 17]. Approximately two-thirds of the boys and girls (about 67%) in our cohort were classified as having low difficulties. Although some studies reported gender-specific trajectories for boys and girls [24, 17, 27], we found similar trajectories for general mental health problems in the two genders, as was also shown in some previous studies [21]. According to our findings, there was a difference in the slope of declining symptoms between boys and girls in the high difficulties class. Girls experienced a steeper decline of mental health problems than boys (from baseline to Wave 2). This may reflect at least partially that girls are more likely to seek help than boys. The second large trajectory in our findings included boys and girls with initial medium difficulties that decreased over the follow-up period of ten years. This was observed not only from preschool age to pre-adolescence, but a decreasing trend was also seen from pre-adolescence to adolescence. These observations are in contrast with findings by Parkes et al. [21] demonstrating a medium increasing trajectory among children from preschool to about 8 years of age. The different age groups and the use of the internalizing subscale of the SDQ in the Parkes et al. study may explain the differences.

Most of the boys and girls showed low symptoms of ADHD and even some improvement over the three time points. Similar findings were reported in earlier work [39, 41]. In line with the age-related decline in ADHD symptoms [68, 69, 31], two classes of ADHD symptom trajectories (medium and high symptoms) were identified among boys and girls in the current study, indicating decreasing trajectories for children and adolescents with high and medium scores of ADHD symptoms. However, the high symptom trajectory (after a decline) showed a high score of ADHD symptoms, especially for boys. A smaller percentage of boys (2.6%) and girls (11.6%) had an increasing pattern of ADHD symptoms. Over three time points, the linear lines showed a rising trend for both genders. However, the quadratic lines demonstrated that the level of ADHD symptoms increased from baseline to Wave 1 with a steeper slope for boys. Then, the trend from the preadolescent age (Wave 1) to adolescence (wave 2) was stable for boys while slightly declining for girls. These findings differ to some extent from earlier work by Murray et al, who showed that symptoms of ADHD as measured by the SDQ-H/I subscale increased to clinically significant levels by the time the age of 14 years was reached [39]. However, this study did not report results separately for boys and girls.

The presented data showed a 3-class model for PA in boys and a 4-class model in girls**.** Most of the boys and girls were categorized as belonging to the increasing and decreasing category of PA. The latter fits with reports that PA declines during the transitional period from childhood to adolescence [70]. Additionally, the second large class in both boys and girls was the class, where individuals experienced a decreasing trajectory after beginning with a high level of PA. The results were consistent with earlier studies that demonstrated a general decline in PA among children and adolescents [71, 72]. In addition to adolescent development changes, the decline in PA may be caused by a changing lifestyle (i.e. more sedentary behavior), altered transportation patterns, effects of industrialization, and an increased use of technology including tablets, mobile devices, and computers [73].

Contrary to expectations, we could not find a significant association between long-term trajectories of general mental health problems or ADHD symptoms on the one hand and PA trajectories on the other. In two earlier cross-sectional and longitudinal follow-up studies [29, 30], it was shown that high weekly PA may play a protective role concerning general mental health problems and ADHD symptoms. Unfortunately, in our trajectory study there was no trajectory group with a continuously high-level of PA; instead, PA trended to wax and wane. This fact might have contributed to a loss of the basically positive effect of PA on mental health problems. Probably, continuously practicing PA could be beneficial for developmental mental health.

**Strengths and limitations**

One of the strengths of the current longitudinal study is the use of a reasonably large population sample size across a wide age range - from preschoolers to adolescents - at various time points to determine the trajectories of variables in a longitudinal approach. Another strength is that it examines the associations between different developmental trajectories (i.e. general mental health problems, ADHD symptoms) with PA. There are also some limitations. First, PA was measured with a single question, which produced a categorical variable. Hence, we could not use conventional joint trajectory methods to look at the concurrent trajectories between a categorical variable (PA) and continuous variables like SDQ-total or ADHD symptoms. Nevertheless, an adequate statistical approximation was applied. The second study limitation was the low entropy values of the models, which ranged from 0.53 to 0.68. Since there is no clear cut-off value for entropy, we considered other indicators before selecting a model [74]. The third limitation is that the study used only data from parent-reported questionnaires to determine general mental health

and ADHD symptoms. Additionally, we did not include weighted factors in the analyses, which means that our results are not entirely representative of the German population. Further work is recommended on concurrent trajectories using multiple informants for developmental psychopathology and objective methods (e.g. accelerometer) to register PA data.

**Conclusion**

In summary, this paper highlights the heterogeneity of developmental trajectories for general mental health problems, ADHD symptoms and PA in children and adolescents of both genders. Our findings provide further evidence that developmental psychopathological features should be considered not only in a cross-sectional manner, but also in terms of long-term developmental changes to better tailor diagnostic and treatment strategies to the individual.

**Author contributions** Conceptualization, P.G.; formal analysis, P.G., Y.H.; methodology, P.G., Y.H.; writing—original draft, P.G.; writing—review and editing, P.G., A.R., Y.H., T.M., N.v.S., U.R.-S., R.K., A.B.; supervision, A.R. All authors have read and agreed to the published version of the manuscript.

**Funding** No specific grant was given to this research by any funding organization in the public, private, or nonprofit sectors.

**Availability of data and materials** The datasets analyzed during the current study are available from the corresponding author on reasonable request.

**Declarations**

**Conflict of interest** All authors declare no conflict of interest.

**Ethics approval** The KiGGS study complied with the Federal Data Protection Act and the EU General Data Protection Regulation (GDPR) (BDSG). The ethics committee at Charité Universitätsmedizin Berlin has given its approval for the KiGGS Baseline (No. 101/2000) and Wave 1 (No. EA2/058/09). The ethics committee at Hannover Medical School reviewed and approved KiGGS Wave 2 (No. 2275-2014).

**Informed consent** All participants and/or their guardians gave their informed consent.

**Acknowledgment** We are grateful to individuals who participated in the KiGGS study as well as their families. The authors would like to express their gratitude to the KiGGS study team at the

Robert Koch Institute for their assistance. Thanks go also to the Georg-August-University of Goettingen, Germany, for support in open-access publishing of this study.

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## Appendix A. Model fit indices of LCMM with group size of classes for SDQ-total and ADHD symptoms in boys and girls

Table A1. Model fit indices to identify trajectory classes of SDQ-total in boys

| | LogLik | BIC | AIC | Entropy | Class 1 | Class 2 | Class 3 | Class 4 | Class 5 |
|---|---|---|---|---|---|---|---|---|---|
| Class 1 | -42457.84 | 84951.88 | 84923.68 | 1.00 | 100.00 | | | | |
| Class 2 | -41284.77 | 82641.94 | 82585.54 | 0.75619 | 16.6490 | 83.3509 | | | |
| Class 3 | -40965.42 | 82039.44 | 81954.84 | 0.6920 | 28.3667 | 5.7649 | 65.8682 | | |
| **Class 4** | **-40859.99** | **81864.77** | **81751.97** | **0.6700** | **24.5039** | **67.6059** | **4.6495** | **3.2405** | |
| Class 5 | -40775.91 | 81732.82 | 81591.83 | 0.6581 | 1.8081 | 63.6022 | 26.4412 | 4.2503 | 3.8980 |

Table A2. Model fit indices to identify trajectory classes of SDQ-total in girls

| | LogLik | BIC | AIC | Entropy | Class 1 | Class 2 | Class 3 | Class 4 | Class 5 |
|---|---|---|---|---|---|---|---|---|---|
| Class 1 | -40654.70 | 81345.48 | 81317.40 | 1.00 | 100.00 | | | | |
| Class 2 | -39557.28 | 79186.72 | 79130.56 | 0.7476 | 82.6639 | 17.3360 | | | |
| Class 3 | -39257.68 | 78623.60 | 78539.36 | 0.7173 | 23.8688 | 72.1025 | 4.0285 | | |
| **Class 4** | **-39124.53** | **78393.37** | **78281.06** | **0.6878** | **3.4478** | **67.2876** | **25.3205** | **3.9438** | |
| Class 5 | -39037.69 | 78255.77 | 78115.37 | 0.6296 | 3.6051 | 2.4921 | 24.0987 | 60.5008 | 9.3031 |

Table A3. Model fit indices to identify trajectory classes of ADHD symptoms in boys

| | LogLik | BIC | AIC | Entropy | Class 1 | Class 2 | Class 3 | Class 4 | Class 5 |
|---|---|---|---|---|---|---|---|---|---|
| Class 1 | -31067.13 | 62170.47 | 62142.26 | 1.00 | 100.00 | | | | |
| Class 2 | -30176.66 | 60425.73 | 60369.32 | 0.6086 | 23.9178 | 76.0821 | | | |
| Class 3 | -29914.28 | 59937.17 | 59852.56 | 0.5936 | 40.7390 | 51.1319 | 8.12903 | | |
| **Class 4** | **-29866.68** | **59878.17** | **59765.36** | **0.5778** | **39.2375** | **7.30791** | **50.8504** | **2.60410** | |
| Class 5 | -29793.93 | 59768.87 | 59627.86 | 0.5572 | 5.1378 | 47.8944 | 2.4398 | 35.7653 | 8.7624 |

Table A4. Model fit indices to identify trajectory classes of ADHD symptoms in girls

| | LogLik | BIC | AIC | Entropy | Class 1 | Class 2 | Class 3 | Class 4 | Class 5 |
|---|---|---|---|---|---|---|---|---|---|
| Class 1 | -29217.33 | 58470.74 | 58442.65 | 1.00 | 100.00 | | | | |
| Class 2 | -28216.56 | 56505.30 | 56449.13 | 0.6942 | 78.4730 | 21.5269 | | | |
| Class 3 | -27960.12 | 56028.49 | 55944.23 | 0.6604 | 31.2515 | 5.7743 | 62.9741 | | |
| **Class 4** | **-27879.83** | **55904.00** | **55791.66** | **0.5826** | **11.6211** | **62.2010** | **5.7985** | **20.3793** | |
| Class 5 | -27813.29 | 55807.00 | 55666.58 | 0.5899 | 2.4039 | 20.2826 | 50.2899 | 4.6146 | 22.4087 |

**Appendix B. The fit indices and group size of classes for LCMM model of PA in boys and girls**

Table B1. Model fit indices to identify trajectory classes of PA in boys

| | LogLik | BIC | AIC | Entropy | Class 1 | Class 2 | Class 3 | Class 4 |
|---|---|---|---|---|---|---|---|---|
| **Class 3** | **-15544.22** | **31197.38** | **31112.45** | **0.5314** | **1.4279** | **58.3162** | **40.255** | |
| Class 4 | -15521.05 | 31187.33 | 31074.09 | 0.5403 | 0.1941 | 65.5471 | 27.4274 | 6.8311 |

Figure B1. PA trajectories for boys for the three-class model

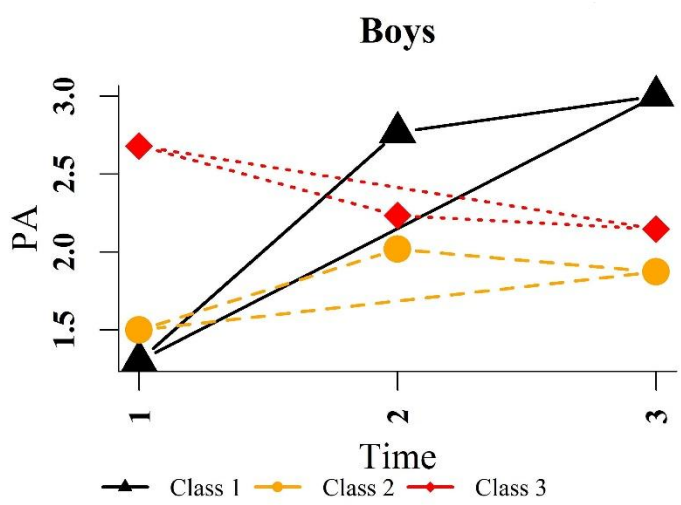
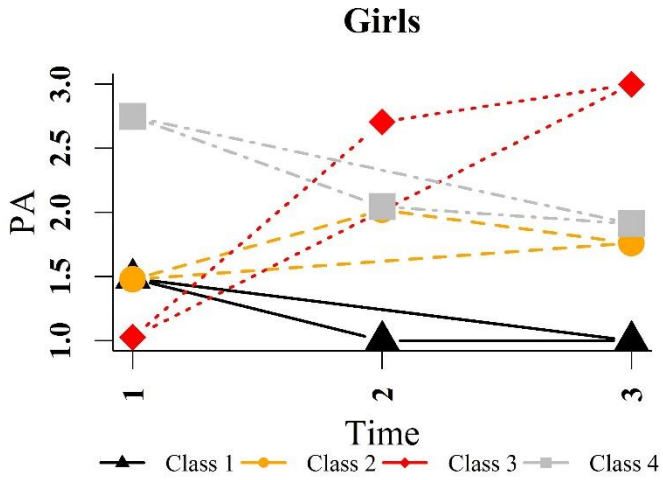



Table B 2. Model fit indices to identify trajectory classes of PA in Girls

| | LogLik | BIC | AIC | Entropy | Class 1 | Class 2 | Class 3 | Class 4 |
|---|---|---|---|---|---|---|---|---|
| **Class 4** | **-15330.32** | **30805.25** | **30692.63** | **0.6082** | **1.3773** | **71.4913** | **0.6649** | **26.4664** |

Figure B1. PA trajectories for girls for the four-class model



# Chapter 4 - Summary Discussion

## 4.1 Research Findings and Comparison to Existing Evidence

This cumulative project on developmental psychopathology examined the cross-sectional, longitudinal, and concurrent developmental associations between PA and mental health problems. The data consisted of a large sample of children and adolescents from a population survey (the KiGGS study). The new findings improved the understanding of the aforementioned relationships, and, as a consequence, practical suggestions for the use of medium/high PA in youngsters could be given.

The dissertation found that increased PA was cross-sectionally and at least at some time points longitudinally linked to improved general mental health and a less symptoms of hyperactivity and inattention. However, over the longitudinal course of ten years, there was no significant association between the concurrent developmental trajectories of general mental health, ADHD symptoms, and PA.

### 4.1.1 Relationship between PA and General Developmental Psychopathology

The first study aimed to address whether there is a link between general mental health problems and PA in different age groups. The study discovered that compared to those with low levels of PA, children with high levels of PA demonstrated lower scores for mental health problems during preschool, school age, and adolescent stages. This relationship was observed at Baseline, Wave 1, and Wave 2. The low to medium effects sizes found in the cross-sectional analyses of PA on mental health problems in preschool, school children, and adolescents were consistent with earlier findings of a systematic review among children and adolescents aged 5 to 17 (Dale et al., 2019). Other studies also showed PA (sport participants) as a positive predictor on mental health in preschool and school children (Vella et al., 2019), and association between inactivity and anxiety, depression, internalizing and externalizing disorders (Bélair et al., 2018; Wu et al., 2018).

In contrast to studies (O'Brien et al., 2020; Rodriguez-Ayllon et al., 2019) that found no association between PA and mental health issues in school-aged children, our findings revealed better mental health for high PA versus low PA in 4-5- and 6-9-years groups at Baseline and Wave 1. This suggests that high levels of PA, as opposed to low and medium levels, may act as a protective factor against mental health problems in preschool and elementary school children. Unexpectedly, high levels of PA were linked to higher scores of difficulties in the 10–17-year-old

age groups compared to medium levels of PA. The type of PA (organized vs. recreational) that teenagers engage in as well as the dose-response effect might play a role on the complex link between PA and mental health problems in adolescents (Gallego-Méndez et al., 2020; McMahon et al., 2017; Wu et al., 2018).

The confirmed cross-sectional relationship between PA and mental health problems at different time-points of development provides a basis for further longitudinal investigations. The second study was conducted to determine if there is a link between PA and general mental health problems over a 10-year period. PA demonstrated a significant inverse connection with subsequent general mental health difficulties after controlling for autoregressive pathways, preceding mental medical problems, time-variant, and time-invariant covariates. Evidence could be found supporting PA at Baseline as a predictor of general mental health problems at Wave 1, i.e. after roughly 6 years. This is consistent with previous research (Doré et al., 2019; Gómez-Baya et al., 2020; Loewen et al., 2019; Wu et al., 2021).

These effects were not observed in our analyses for the cross-lagged association between Wave 1 and Wave 2 (i.e., during adolescence) in either boys or girls. However, it could be shown that adolescents with low activity levels or inactivity undergo more emotional difficulties and depressive symptoms (Bell et al., 2019; Bowe et al., 2021; Gómez-Baya et al., 2020; Kandola et al., 2020). The adolescent years are a special time in a person's life. Many changes take place at multiple levels (e.g. neurological, physiological, and psychosocial). The long-term impact of PA on teenagers' mental health problems could be mitigated by a variety of factors, like hormonal changes, struggles with identity, a desire to become independent, and being accepted by peer groups.

While applying structural equating modeling, it is possible to find the reciprocal effects that PA and general mental health may have on each other. For example, in our study, the higher path coefficients that go from PA to SDQ-total than vice versa, indicate that PA can be a more reliable predictor of mental health problems than mental health problems for PA. Our longitudinal follow-up findings from Baseline to Wave 1 were consistent for both boys and girls. As a possible consequence, a high level of PA may be recommended for both genders, especially in the long run for younger children.

The objective of the third study was to investigate the correlation between the developmental trajectories of general mental health problems and PA. Findings of distinct trajectories for general mental health problems among boys and girls was in complete agreement with earlier studies

(Flouri et al., 2018; Nivard et al., 2017; Patalay et al., 2017; Shore et al., 2018), which reported a heterogeneity of developments of mental health problems among children and adolescents. A group with low scores and a decreasing trend of general mental health problems included the greatest number of boys and girls and supports previous findings (Lewis et al., 2020; Vella et al., 2019). The same trajectories for both sexes in our investigation is not in line with previous research (Lewis et al., 2020; Shore et al., 2018; Vella et al., 2019) that showed differences between boys and girls in this respect. However, a subgroup of girls with initially high SDQ-total scores had a steeper decline than boys, which might be explained by the clinical experience that parents of girls maybe seeking help earlier and more often.

We did not find any significant relationship between trajectories of SDQ-total and different trajectories of PA among boys and girls. Despite PA's cross-sectional and longitudinal follow-up effects on improving mental health problems, this finding might be best explained by the fact that the majority of children and adolescents were in the "decreasing and increasing" trajectory of PA, while fewer participants were in the other groups. This imbalance might have an impact on the statistical relationships between the PA and SDQ-total trajectories. Also, unknown factors might come into play during developmental trajectories when otherwise negligible problems might act steadily over time.

### 4.1.2 Relationship between PA and ADHD Symptoms

In the first study, which focused on examining the correlation between ADHD symptoms and PA in various age groups, our cross-sectional analysis revealed that children who were at medium or high levels of PA exhibited significantly fewer ADHD symptoms than those who were at a low level. These findings are consistent with findings from experimental studies (Da Silva et al., 2020; Mehren et al., 2020; Miklós et al., 2020) that showed a favorable effect of PA in children with ADHD. High PA levels were significantly associated with fewer ADHD symptoms in preschool and primary school children at Baseline and Wave 1. However, the results addressing the difference between low and medium levels of PA were not significant among children in this age group. Several studies (Hartman et al., 2019; Van Egmond-Fröhlich et al., 2012) revealed a positive association between PA and ADHD symptoms, indicating that a high level of PA is associated with more ADHD symptoms. Our analyses also revealed that adolescents (10–17 years old) with high versus medium levels of PA displayed significantly more ADHD symptoms at three different time points. Whether this reflects a report-bias of parents who are not the best raters/observes for

adolescents (in contrast for children) or whether other factors have to be taken into account needs to be investigated in the future.

In the second study, the objective was to investigate whether there is a link between ADHD symptoms and PA over a ten-year period. The results indicate that increased levels of PA are associated with a reduction in ADHD symptoms in the following time point, which was approximately six years later, from Baseline to Wave 1. However, these effects were not found in the subsequent period from Wave 1 to Wave 2 for both boys and girls. The cross-lagged analyses of adolescents revealed that higher levels of PA were associated with increased ADHD symptoms at the subsequent time point (from Wave 1 to Wave 2). This was the case regardless of whether the adolescents were boys or girls. This is consistent with the findings of previous research in adolescents that an increase in PA was connected to a higher score on the SDQ-H/I or that PA was a predictor for increased ADHD symptoms (Ahn et al., 2018; Brandt et al., 2021; Wiles et al., 2008). Probably, distinguishing between the frequency, duration, and intensity of PA as well as integrating methodological aspects like measurement of PA in studies might be able to explain the results. Girls who exhibited higher levels of ADHD symptoms had significantly lower PA levels approximately four years later. Therefore, a suggestion could be made that adolescent girls who suffer from severe ADHD should be encouraged to exercise at a high-level of PA in order to support their mental health.

To address the third research question, which sought to investigate the potential relationship between the developmental trajectories of ADHD symptoms and PA, our analysis did not reveal any significant associations between these trajectories in either boys or girls. However, the finding that most boys and girls belonged to the sub-group trajectory with low ADHD symptoms matches well with earlier evidence of population cohort studies (Forte et al., 2020; Murray et al., 2021). ADHD symptoms decreased stronger in girls. This doesn’t fit with their findings that ADHD had a steeper decline in boys (Wootton et al., 2022). Despite studies showing a general age-related decline for ADHD (Thapar & Riglin, 2020; Vergunst et al., 2019; Wootton et al., 2022), we found a small subgroup of girls and boys with increasing symptoms. Therefore, individual differences of the course should be considered.

## 4.2 Strengths and Limitations

It is important to take into account the strengths of this cumulative study. We took advantage of the KiGGS study's large-scale and substantial sample size of children and adolescents (from preschoolers to adolescents aged 17 years), which allowed us to undertake detailed statistical analyses at three consecutive time points over the course of 10 years. The use of the SDQ as a valid multidimensional instrument to evaluate the general mental health problems and ADHD symptoms was another strength. The investigational sequence, which consisted of dividing the analyses into three parts (cross-sectional, longitudinal and trajectory relationship), increased both the validity, accuracy, and robustness of the findings of this dissertation. In the *first study*, three distinct developmental age groups were analyzed using GLM approaches at three different points in time. Finding consistent results by using three age groups that were independent of one another allowed for conclusions that could help to resolve some of the uncertainties from previous research regarding the relationship between mental health problems and PA. In the *second study*, longitudinal models with an autoregressive cross-lagged design were used. The results of this analysis provided good evidence of the benefits of PA on mental health problems and ADHD symptoms. In the *third study*, we investigated the relationship between different developmental trajectories using a latent class mixed model. According to our knowledge, this was the first study which looked at the concurrent developmental trajectories of both general and specific mental health problems with PA trajectories.

This cumulative work, however, has also some limitations that should be taken into consideration when reviewing the findings. In the present study, because of our preschool/early-elementary-school age group and the large sample size of a general population, only a parent questionnaire was administered to a population sample of children and adolescents in order to evaluate mental health problems. However, parent information is the best proxy of what can be gathered with a multi-informant approach, at least for preschoolers and children in elementary school. Using mixed report of PA was justified by findings of low agreement between parent-report and self-report of PA for adolescents is another limitation. The mixed report means using parental reports for children under age 11 and self-reports for older children. Additionally, we employed a compound variable for PA at Baseline, while we used a WHO-based variable for PA at Wave 1 and Wave 2. Changing the variables to assess PA was a decision taken by the designers of the KiGGS study. Furthermore, due to the type of PA variable, which was categorical, there were some

limitations in selecting and conducting statistical analyses. In Study 3 we were not able to use common joint trajectory methods. Finally, because no weighting factor was used in the analysis, the results are not fully representative of the German population. Although the longitudinal design of the KiGGS study did not allow for strong causal inferences, it did give indications of causality when a longitudinal analysis was used, as in studies 2 and 3 of this dissertation. For more limitations please refer to the Limitations sections of papers.

## 4.3 Prospects for Future Research and Clinical Practice

The current cumulative work, evaluated cross-sectional, longitudinal and concurrent developmental relationship between general mental health problems and specific psychopathology (ADHD symptoms) with PA in children and adolescents. The findings indicated that PA, particularly in preschool- and school-aged children of both sexes, can be thought of as a protective factor against mental health issues and symptoms of ADHD. Moving forward, there are several avenues for future research that can further expand our understanding of the topic at hand. Firstly, additional investigations could be conducted to by investigating the type and intensity of PA using questionnaires and/or objective research methods (e.g. accelerometer). Secondly, future research should make use of large sample sizes with a longitudinal design, such as ours, and should consider additional time varying covariates, like behaviors and psychosocial factors that they are more likely to appear in adolescents ages (starting smoking or using alcohol) (Bélair, 2018), physical selfconcept, and quality of sleep (Rodriguez-Ayllon, 2019). This will allow researchers to gain a better understanding of the role that PA plays in the prevention and even treatment of mental health problems during the development of children and adolescents. Thirdly, only some of the participants reported also a diagnosis of ADHD by professional clinical assessment; for future research a complete clinical assessment is recommended wherever possible and indicated by initial screening because analyzing data from two sources (a reliable questionnaire and physician or psychologist diagnosis) underlines the robustness of findings.

Based on the findings of this cumulative thesis, several recommendations may be made for clinical practice. Firstly, healthcare professionals working with children and adolescents consider the potential benefits of PA in promoting mental health and reducing ADHD symptoms. Clinicians may encourage their patients (especially among youngsters) to engage in regular PA and provide them with resources and support to do so. Secondly, healthcare professionals may consider the potential differential effects of PA on mental health outcomes among subgroups of children and

adolescents and tailor their recommendations accordingly (different age groups: preschool children, schoolchildren, and adolescents). Thirdly, given the potential benefits of PA in improving mental health outcomes, policymakers should prioritize the promotion of PA in schools and communities as per WHO recommendations.

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## Acknowledgements

In the first place, I would like to express my deepest appreciation and gratitude to my supervisor Prof. Aribert Rothenberger for his outstanding, consistent, and comprehensive assistance not only in work but also in life during the entirety of my doctoral studies. I could not have undertaken this fruitful journey without his priceless patience, understanding and feedback. In light of his expertise and encouragement, I was able to gain a lot of knowledge, and I was also inspired to pursue my desire in the future by going into research and psychotherapy. I would like to express my sincere gratitude to Prof. York Hagmayer and Prof. Nicole von Steinbüchel, members of my thesis committee, for all of the recommendations that were provided during my committee meetings as well as pleasant atmosphere that prevailed throughout those meetings. I discussed early statistical parts of the papers with Prof. York Hagmayer and always he raised many precious points in our discussion and devoted time to my project. I'd also like to extend my special thanks to Prof. Thomas Meyer, for the kind assistance he provided to me while I was preparing the papers. For their guidance and management with my PhD program, I am grateful to my former and present program promoters, Professor Martin Oppermann, Professor Ralf Dressel, and Ms. Kornelia Ewens of the Promotion Office. I am also grateful to Dr. Andreas Becker for his valuable help and support in the clinic for child and adolescent psychiatry and psychotherapy during my study. Especially I am extremely grateful to Dr. Eva-Maria Kollhoff who generously offers her help and support in my life. I would like to thank Dr. Henrik Uebel-von Sandersleben and Dr. Benjamin Schmid to support me in earning wonderful experience with taking part in therapy and psychology sessions in the clinic. I am thankful of all other colleagues in the clinic Prof. Luise Poustka, Dr. Corinna Isensee, Ms.Fatmeh Al-Deb'I**,** Ms. Ute Bolt, and Ms. Annika Riehn who help me when I need during the past four years.

I also want to thank my wonderful office mates, past and present, Dr. Biyao Wang, Ms. Susan Högg, Ms. Clara Meigen, and Ms. Sophie Schmitz for being such kind companions. I want to express my gratitude to Dr. Kuhnert and Prof. Ulrike Ravens-Sieberer for their assistance with the study. The KiGGS research participants and their families deserve my gratitude as well. The research concepts and work from this thesis would not be possible without the efforts of the management team, cohort coordination team, and KiGGS study team from the Robert Koch Institute, who generously provided us with their data file. Additionally, I appreciate my friend Mr. Ali-reza Baneshi, who always allows use of his statistical knowledge and willingly answers my

questions. My family and amazing friends from Iran to Germany have always been there for me with their endless love and unwavering support in all of my endeavors, and I would like to offer my sincere appreciation to them. You give me meaning and purpose, and I love you too.