Physical Activity and Health in Children and Adolescents in Germany

An Analysis of the MoMo Data

Simon Kolb

Karlsruher Institut für Technologie

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by
Simon Kolb

Karlsruhe Institute of Technology

Karlsruher Institut für Technologie
Institut für Sport und Sportwissenschaft

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Zur Erlangung des akademischen Grades eines Doktors der Philosophie (Dr. phil.) von der KIT-Fakultät für Geistes- und Sozialwissenschaften des Karlsruher Instituts für Technologie (KIT) genehmigte Dissertation

von Simon Kolb

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Institute of Sports and Sports Science (IfSS)
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Zusammenfassung

Die vorliegende Dissertation thematisiert den Zusammenhang zwischen der körperlichen Aktivität und der Gesundheit von Kindern und Jugendlichen. Die Analyse und Darstellung der Zusammenhänge erfolgt unter Verwendung der Daten der Motorik-Modul-Längsschnittstudie (MoMo). MoMo ist eine bundesweite Studie, die sich mit der motorischen Leistungsfähigkeit, der körperlichen Aktivität und der Gesundheit von Kindern und Jugendlichen befasst. Die ursprüngliche Konzeption der Studie erfolgte als vertiefendes Teilmodul mit den genannten Schwerpunkten der Studie zur Gesundheit von Kindern und Jugendlichen in Deutschland (KiGGS) des Robert-Koch-Instituts (RKI). Auf die Basiserhebung in den Jahren 2003 bis 2006 folgten zwei weitere Erhebungswellen (Welle 1: 2009 bis 2012, Welle 2: 2014 bis 2017). Die Datenerfassung im Rahmen von MoMo umfasst sportmotorische Tests, anthropometrische Messungen sowie Fragebögen zum Bewegungsverhalten. Seit der zweiten Welle werden die Fragebögen um Beschleunigungssensoren ergänzt. Seit 2017 wurden keine weiteren Erhebungen durch das RKI durchgeführt, jedoch wurde 2018 die dritte Folgeuntersuchung von MoMo (Welle 3) initiiert. Aufgrund der Corona-Pandemie mussten die Untersuchungen im Feld im März 2020 eingestellt werden. Ab Herbst 2021 wurde die Welle mittels Onlinebefragung und videobasierter Testungen fortgeführt und Anfang 2022 abgeschlossen.

Der erste Artikel der vorliegenden Dissertation ist eine Überblicksarbeit mit dem Titel *Indicators to Assess Physical Health of Children and Adolescents in Activity Research - A Scoping Review* Kolb et al., 2021. Der Artikel verfolgt den Grundgedanken, die in der Aktivitätsforschung genutzten Indikatoren zu analysieren, die zur Untersuchung der Wirkung körperlicher Aktivität auf die Gesundheit von Kindern und Jugendlichen herangezogen werden. Im Fokus stand dabei die Frage, auf welche Art und Weise Gesundheit quantifiziert wird und somit die grundlegende Frage, was im vorliegenden Kontext unter Gesundheit verstanden wird. Aufgrund der Breite des Feldes wurde der Fokus der Analyse auf Überblicksarbeiten zur Auswirkung körperlicher Aktivität auf die körperliche Gesundheit gelegt. In den 32 systematischen Reviews, die in die Analyse eingeschlossen wurden, wurde die körperliche Gesundheit der untersuchten Kinder und Jugendlichen zumeist durch die Körperzusammensetzung, kardiometabolische Biomarker, körperliche Fitness, Schädigungen/Verletzungen sowie Knochengesundheit abgebildet. Die Analyse

ergab, dass die Körperzusammensetzung am häufigsten als Indikator der körperlichen Gesundheit verwendet wurde. Es wurde jedoch auch festgestellt, dass in den einzelnen Studien unterschiedliche Variablen für die Konstrukte verwendet wurden. So erfolgt die Messung der Körperzusammensetzung beispielsweise anhand des BMI, des Körperfettanteils oder des Taillienumfangs.

Der zweite Artikel der vorliegenden Dissertation widmet sich der Thematik des Zusammenhangs zwischen körperlicher Aktivität und rezidivierenden Schmerzen (Kolb et al., 2022). Diese können eine signifikante Einschränkung des Wohlbefindens darstellen und treten bereits im Kindes- und Jugendalter auf. In der vorliegenden Analyse wurden wiederkehrende Kopf-, Bauch- und Rückenschmerzen untersucht, da diese laut früheren Untersuchungen die häufigsten Arten wiederkehrender Schmerzen in der Zielgruppe bilden. Es konnte eine höhere Prävalenz bei den Teilnehmerinnen im Vergleich zu den männlichen Teilnehmern festgestellt werden. Zusätzlich wurde eine erhöhte Prävalenz bei den Teilnehmerinnen festgestellt, wobei auch eine höhere Prävalenz bei den Teilnehmenden beider Geschlechter beobachtet wurde, die im Durchschnitt weniger als 60 Minuten körperliche Aktivität mit mindestens moderater Intensität pro Tag aufwiesen. Zudem wurde festgestellt, dass Mädchen, die wiederkehrende Kopfschmerzen aufwiesen, im Durchschnitt etwa fünf Minuten weniger körperliche Aktivität mit mindestens moderater Intensität pro Tag aufwiesen.

Der dritte Artikel der vorliegenden Dissertation beleuchtet den Zusammenhang zwischen körperlicher Aktivität und Gesundheit im Zeitverlauf (Kolb et al., 2025). Zu diesem Zweck wurden ausgewählte Gesundheitsparameter der Teilnehmerinnen und Teilnehmer analysiert, die sowohl an der Basisuntersuchung (2003–2006) als auch an der ersten Folgeerhebung (2009–2012) teilgenommen hatten. Die Einteilung der Teilnehmer und Teilnehmerinnen in Gruppen erfolgte auf der Grundlage ihrer sportlichen Aktivität im Verein. Als Grenzwert wurde der Median der Gruppe von 240 Minuten pro Woche gewählt, was die Bildung von vier Gruppen zur Folge hatte, die miteinander verglichen wurden. Die erste Gruppe umfasste die konstant hochaktiven Teilnehmer und Teilnehmerinnen, die an beiden Messzeitpunkten den Grenzwert übertrafen. Die zweite Gruppe setzte sich aus den Teilnehmern zusammen, die sich durch eine konstant niedrige sportliche Aktivität auszeichneten und zu beiden Messzeitpunkten weniger als 240 Minuten pro Woche im Verein aktiv waren. Schließlich wurden zwei weitere Gruppen gebildet: die der Wechsler. Die Analysen ergaben signifikante Unterschiede zwischen den Gruppen bei der zweiten Untersuchung in Bezug auf die körperliche Fitness und in Bezug auf wiederkehrende Kopfschmerzen, jedoch nicht für den BMI. Die Gruppe der Hochaktiven zeigte bessere Ergebnisse in der Ausdauerleistungsfähigkeit und der Kraftausdauer der oberen Extremitäten als die Niedrigaktiven und die Reduzierer. Beim Standweitsprung schnitten die Hochaktiven signifikant besser ab als alle drei anderen Gruppen. Die konstant Niedrigaktiven, die Reduzierer sowie die Steigerer wiesen im Vergleich zu den Hochaktiven ein erhöhtes Risiko für wiederkehrende Kopfschmerzen auf. Die Studie kommt daher zu dem Ergebnis, dass die kontinuierliche Teilnahme am Vereinssport den größten gesundheitlichen Nutzen bringt. Gleichzeitig konnte gezeigt werden, dass eine Steigerung der Vereinssportaktivität zu positiven Effekten führt und somit auch Kindern und Jugendlichen mit geringer oder keiner Sportaktivität die Chance bietet, positive Gesundheitseffekte zu erzielen.

Die Ergebnisse des zweiten und dritten Artikels unterstreichen die Bedeutung der körperlichen Aktivität für die Gesundheit von Kindern und Jugendlichen. Auf Basis dessen ist eine kontinuierliche Erfassung im Rahmen eines Gesundheitmonitorings inklusive des Bewegungsverhaltens immens wichtig. Das es sich dabei keinen Falls um eine einfache Aufgabe handelt, ist ebenfalls ersichtlich. Sowohl die körperliche Aktivität als auch die Gesundheit sind komplexe Konstrukte mit einer Vielzahl von Einflussfaktoren. Nur durch eine interdisziplinäre Herangehensweise kann diese Herausforderung gelöst werden.

Summary

This dissertation addresses the relationship between physical activity and the health of children and adolescents. The analysis and presentation of the relationships are based on data from the Motorik Modul Longitudinal Study (MoMo). MoMo is a nationwide study that focuses on motor skills, physical activity, and the health of children and adolescents. The original conception of the study was carried out as an in-depth sub-module with the above-mentioned priorities of the study on the health of children and adolescents in Germany (KiGGS) by the Robert Koch Institute (RKI). The baseline survey conducted between 2003 and 2006 was followed by two further survey waves (wave 1: 2009 to 2012, wave 2: 2014 to 2017). Data collection for MoMo includes sports motor skills tests, anthropometric measurements, and questionnaires on physical activity behavior. Since the second wave, the questionnaires have been supplemented by accelerometers. No further surveys have been conducted by the RKI since 2017, but the third follow-up study of MoMo (wave 3) was initiated in 2018. Due to the coronavirus pandemic, the field studies had to be discontinued in March 2020. Starting in the fall of 2021, the wave continued using online surveys and video-based testing and was completed in early 2022.

The first article of the present dissertation is a review paper entitled *Indicators to Assess Physical Health of Children and Adolescents in Activity Research - A Scoping Review* (Kolb et al., 2021). The article pursues the basic idea of analyzing the indicators used in activity research to examine the effect of physical activity on the health of children and adolescents. The focus was on the question of how health is quantified and thus the fundamental question of what is meant by health in the present context. Due to the breadth of the field, the focus of the analysis was placed on reviews of the impact of physical activity on physical health. In the 32 systematic reviews included in the analysis, the physical health of the children and adolescents studied was mostly assessed using body composition, cardiometabolic biomarkers, physical fitness, injuries, and bone health. The analysis showed that body composition was the indicator of physical health used most frequently. However, it was also found that different variables were used for the constructs in the individual studies. For example, body composition is measured using BMI, body fat percentage or waist circumference.

The second article in this dissertation is devoted to the topic of the relationship between physical activity and recurrent pain (Kolb et al., 2022). These can significantly impair well-being and already occur in childhood and adolescence. In the present analysis, recurrent headaches, abdominal pain and back pain were examined, as these are the most common types of recurrent pain in the target group according to previous research. A higher prevalence was found among female participants compared to male participants. In addition, an increased prevalence was found among female participants, although a higher prevalence was also observed among participants of both sexes who, on average, performed less than 60 minutes of physical activity at least at a moderate intensity per day. Furthermore, it was found that girls who reported recurrent headaches performed on average about five minutes less physical activity at least at a moderate intensity per day.

The third article in this dissertation examines the relationship between physical activity and health over time (Kolb et al., 2025). To this end, selected health parameters of the participants who had taken part in both the baseline study (2003–2006) and the first follow-up study (2009–2012) were analyzed. The participants were divided into groups based on their sporting activity in the club. The median of the group of 240 minutes per week was chosen as the cut-off value, which resulted in the formation of four groups that were compared with each other. The first group comprised the consistently highly active participants who exceeded the cut-off value at both measurement points. The second group consisted of the participants who were consistently less active and who spent less than 240 minutes per week in the club at both measurement points. Finally, two further groups were formed: the changers. The analyses revealed significant differences between the groups in the second examination in terms of physical fitness and recurring headaches, but not for BMI. The highly active group showed better results in endurance performance and strength endurance of the upper extremities than the low active and the reducers. In the standing long jump, the highly active group performed significantly better than all three other groups. The consistently low active, the reducers, and the improvers showed an increased risk of recurring headaches compared to the highly active group. The study therefore concludes that continuous participation in club sports brings the greatest health benefits. At the same time, it was shown that an increase in club sports activity leads to positive effects and thus also offers children and adolescents with little or no sports activity the chance to achieve positive health effects.

The results of the second and third articles underline the importance of physical activity for the health of children and young people. On the basis of this, continuous recording as part of health monitoring, including physical activity behavior, is immensely important. It is also clear that this is by no means a simple task. Both physical activity and health are complex constructs with a multitude of influencing factors. This challenge can only be solved by taking an interdisciplinary approach.

Preface

This thesis with the title *Physical Activity and Health in Children and Adolescents in Germany* was developed within the Motorik-Modul Longitudinal Study (MoMo)(2009-2022): Physical fitness and physical activity as determinants of health development in children and adolescents in Germany. The MoMo study was supported by the German Federal Ministry of Education and Research (01ER1503) within the long-term research program in public health research.

Motorik-Module Study

As the title of the study - *Motorik-Modul Longitudinal Study: Physical fitness and physical activity as determinants of health development in children and adolescents in Germany* - indicates, the *Motorik-Modul* was designed as part of a bigger framework. In this case, the bigger framework is the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) by the Robert Koch-Institute (RKI). MoMo is a joint project of the Institute of Sports and Sports Sciences (IFSS) of the Karlsruhe Institute of Technology (KIT), the Institute of Movement Education and Sport of the University of Education Karlsruhe (phKA) (since 2011), and the RKI Berlin. In the course of the study, the Department of Sports Science at the University of Konstanz (2009-2014) and the Department of Sport and Exercise at the University of Education Schwäbisch Gmünd (2009-2011) were also involved in conducting the research.

Figure 1: MoMo study logo

In MoMo, different questions on motor performance, physical activity and health are being investigated in order to contribute to the recording and improvement of long-term health in children and adolescents in Germany. Answering the following questions forms the core of the study:

1. How do internal (e.g., age, sex, personal attitudes) and external factors (e.g., influence of peers, parents, socioeconomic level, environment, or migration background) affect the development of physical activity and physical fitness in early and late adolescence?

2. How do physical activity (type, intensity, duration, frequency), internal (age, sex) and external factors (socioeconomic level, environment, migration background) influence the change/development of physical fitness?

3. How well can physical activity and physical fitness predict physical health (e.g., pain, obesity), biochemical risk factors, overall health, mental health, and quality of life later in life?

4. Are there any age-related or periodic effects on physical activity and physical fitness in childhood and adolescence?

MoMo collects both objective data, which are collected by means of standardized test procedures (e.g., motor performance tests) or with the help of sensors (e.g., accelerometer, body composition analyzer), and subjective data, which are obtained via questionnaires (e.g., behaviour) or interviews (e.g., health status). MoMo collects data on motor performance, physical activity and health, as well as on known or suspected influencing factors.

Published research

The core of this dissertation is made up the following articles, which have been published in peer-reviewed journals:

Paper I: Kolb, S., Burchartz, A., Oriwol, D., Schmidt, S.C.E., Woll, A. & Niessner, C. (2021). Indicators to Assess Physical Health of Children and Adolescents in Activity Research - A Scoping Review. *International Journal of Environmental Research and Public Health, 18*(20).

Paper II: Kolb, S., Burchartz, A., Krause, L., Klos, L., Schmidt, S.C.E., Woll, A. & Niessner, C. (2022). Physical Activity and Recurrent Pain in Children and Adolescents in Germany - Results from the MoMo Study. *Children, 9*(11).

Paper III: Kolb, S., Burchartz, A., Klos, L., Jekauc, D. , Niessner, C. & Woll, A. (2025). Association between physical activity and physical health in German children and adolescents - results from the MoMo Longitudinal Study. *BMC Public Health, 25*.

Contents

1 Introduction

"Health may not be everything, but without health, everything is nothing."

This saying of the German philosopher Arthur Schopenhauer (1788-1860) highlights one of the major challenges of health promotion and preventive action in general. As long as you're healthy, there are usually other things that are more important. But when you're not, those other things lose their significance. Whether it is a matter of one's own health or the public health, health is all too often only noticed when it is missing. The subsequent restoration of health involves effort. This usually costs time, whether it is time for recovery or time for medical services. Furthermore, there are costs. Costs for treatment and/or medication, as well as indirect costs due to the loss of working hours and productivity of those affected. And in most cases, the restoration of health affects the normal course of everyday life. Considering that, the ideal solution would be not to get sick in the first place. This way, the individual experiences no restrictions or pain, neither time nor money is needed to restore health, and there are no burdens on society due to the loss of labor.

That's easier said than done. In principle, a distinction must be made between communicable and non-communicable diseases. The former group can be combated by killing the pathogens and restricting or preventing transmission. These "simple" means are not available for non-communicable diseases. These diseases are usually due to genetic disposition and unhealthy lifestyle factors. Since the genetic predispositions are given, lifestyle factors must be addressed in order to prevent non-communicable diseases. To be able to do this, knowledge is needed about the links between lifestyle factors and health. In addition to knowing which factors have a negative impact on health, it is also important to know which factors have a health-promoting effect. The Greek physician and philosopher Hippocrates already recognized the connection between physical activity and health and is said to have stated that all parts of the body that are not used and lie fallow, age faster and grow poorly (Kokkinos and Myers, 2010).

1.1 Background

The health benefits of physical activity include, among other things, a lower risk of cardiovascular disease, high blood pressure and diabetes. It also delays the onset of dementia and can help you maintain a healthy weight (Guthold et al., 2018; Poitras et al., 2016; World Health Organization, 2018; World Health Organization, 2010). Therefore, lack of physical activity is a leading risk factor for noncommunicable diseases and is associated with poor mental health (Guthold et al., 2018). This is a real problem for former hunter-gatherers who had to walk long distances every day to find food or shelter, living in an era when motorized and non-motorized aids are available to cover any distance with little to no effort. Physical inactivity is among the top five causes of death worldwide and the WHO speaks of a global pandemic of physical inactivity (Kohl et al., 2012; Piggin and Bairner, 2016). The effects of the problem of inactivity are manifold and range from restrictions and more difficult participation at an individual level to increased health expenditure and reduced performance at a societal level. Although the health benefits of physical activity have been known for over half a century, the promotion of population health improvement through physical activity lags behind the available evidence (Kohl et al., 2012). The WHO's physical activity recommendations have already been revised (World Health Organization, 2020) and many nations have developed their own physical activity recommendations (Parrish et al., 2020). To support these efforts and create a unified framework to facilitate sustainable improvement, WHO developed the *Global action plan on physical activity 2018-2030: more active people for a healthier world* (GAPPA). It includes four strategic objectives that can be universally implemented in every country, regardless of where it currently stands in terms of reducing physical inactivity (World Health Organization, 2018). These four objectives are: (1) Create active societies, (2) create active environments, (3) create active people, and (4) create active systems. To achieve the four strategic objectives, 20 policy actions are proposed by the WHO (World Health Organization, 2018).

1.2 Importance of physical activity and health research in children and youth

Against this background, it makes sense to research the links between physical activity and health. One target group is particularly important for various reasons: children and adolescents. Childhood and adolescence are characterized by numerous physical and mental developments. In addition to the growth of the body, which is usually clearly visible on the outside, countless other developmental processes take place on the inside. These include motor development, which is closely linked to physical development, and mental maturation. There are also changes on a hormonal level, such as sexual maturity, which in turn has a direct impact on physical development. All in all, the period of life up to young adulthood is characterized by development on a physical, mental or social level, which is associated with changes. These changes occur in a relatively short period of time on various levels and take place simultaneously or successively. Even though, the developmental process is very individual in terms of timing, velocity, or final endpoint, the monitoring is important to detect deviations to prevent negative consequences. Therefore, reference values like percentiles for BMI or time spent engaging in PA are necessary. Delivering such reference values is one aspect of the monitoring process. But, deviations can only be discovered if data about the current state is available. Regular recording of health values, activity behavior and physical fitness as part of holistic monitoring can provide these reference values as well as data for further research into the underlying relationships.

Childhood and adolescents are at the same time the foundation of the later life. Abilities like walking, swimming, climbing, or cycling are acquired during these phases. Some abilities like walking or manipulating objects are a part of the motor development and essential to adapt to challenges of daily life. Others, like swimming or cycling are not mandatory for master everyday tasks, but they are very important for the engagement in PA or sport. Nevertheless, simple skills and their confident mastery are also important because they form the basis for acquiring more complex skills as you develop (Hills et al., 2007).

Furthermore, research shows that, for example, overweight children have an increased risk of being overweight in the future (Herman et al., 2009; Rittsteiger et al., 2022). Such findings suggest that the problem should be tackled as early as possible, or that measures should be taken to prevent it from occurring in the first place. The example of obesity illustrates another reason why children and adolescents are an important target group. If the problem occurs early in life, the risk of negative consequences increases because the person is at risk for a longer period of time.

1.3 Research objectives

The aim of this dissertation is to contribute to a better understanding of the relationships between physical activity and health, especially in children and adolescents. To this end, the work focuses on various issues. The basis of the work is the review with the title *Indicators to assess physical health of children and adolescents in activity research*, which served to summarize the current state of knowledge regarding which parameters are used to investigate relationships between physical activity and physical health. In view of the findings from the review, the data from the MoMo study are used below to describe physical activity and physical health as well as their development and interrelations in children and adolescents in Germany. Both cross-sectional relationships and relationships over time are considered. These objectives lead to the following main research questions for the thesis to answer:

1. RQ1: How is physical health expressed in research on physical activity in children and adolescents?
2. RQ2: What is the relationship between physical activity and physical health among children and adolescents in Germany?

1.4 Structure of the thesis

The document is structured as followed (cf. fig 1.1). The first chapter provides a brief overview of the topic and its relevance. The second section of chapter 1 highlights the particular importance of research on physical activity and health in children and adolescents. At the end of the chapter, the objectives and structure of the work are presented.

The second chapter of the paper is devoted to the theoretical foundations. The two constructs, physical activity and health, are presented, along with a model of the relationship between the two. Part of the theoretical background is also the first article in which the assessment of physical health is examined.

Chapter three presents the MoMo study from which the data for the analyses of the work come. After a brief overview, the sample for the analyses, the data set and the survey instruments are presented.

The fourth chapter of the thesis presents selected data on physical activity and health. First, both constructs are presented using the pooled data set in which each participant occurs only once. This is followed by the second article in which the association between physical activity and recurring pain is examined in a cross-section. The following is a presentation of the development of physical activity and physical health based on the data of participants who took part in MoMo multiple times. The third article, which deals with the relationship between physical activity and physical health over time, will follow.

The discussion section (Chapter 5) summarizes and contextualizes the findings presented in the previous chapters. It also considers the role of physical activity in reducing health risks. After discussing the strengths and weaknesses of the thesis, recommendations for future research are made.

Chapter six presents the conclusion of the work. It summarizes the contribution of the work to research on physical activity and health in children and adolescents in Germany. Subsequently, the implications for health policy and the practical implementation of public health from the findings are presented.

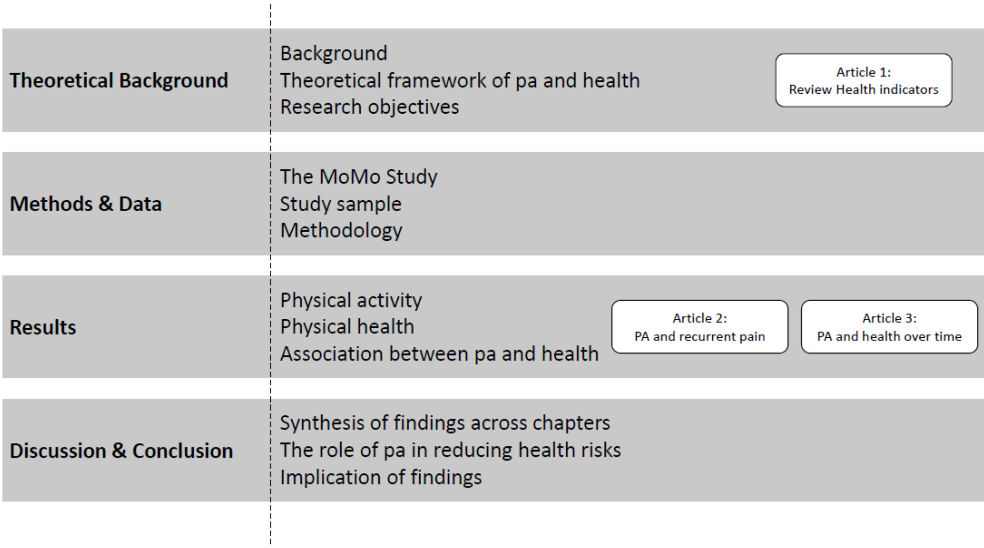


Figure 1.1: Structure of the thesis

2 Theoretical background

The following chapter provides the theoretical foundation of the dissertation. It includes the definitions and characteristics of the two constructs of physical activity and health. It also presents a model of the relationship between physical activity and health.

2.1 Theoretical framework of physical activity and health in youth

2.1.1 Physical Activity

„Physical activity is defined as any bodily movement produced by skeletal muscles that result in energy expenditure. The energy expenditure can be measured in kilocalories. Physical activity in daily life can be categorized into occupational, sports, conditioning, household, or other activities.“ *(Caspersen et al., 1985, p. 126)*

The above definition was proposed by Caspersen, Powell, and Christenson (Caspersen et al., 1985), and since then this understanding of PA has become established in the field of health-related research. According to this definition, PA consists of a *movement* of the body induced by *skeletal muscle activity* that results in an increase of energy expenditure over consumption at rest. Since those aspects apply to walking to school as well as they apply to participating in a cycling race, PA is a broad umbrella term including any kind of movement. Nevertheless, in German-speaking countries in particular the translation leads to inaccuracies or confusion, since here a linguistic distinction is made between movements in everyday life (e.g., climbing stairs or carrying loads) and sporting activities (e.g., swimming, cycling). Moreover, the German meaning of *sport* is a broader understanding including perspectives of health or (self-)experience in addition to the traditional aspects such as competition and performance. Last but not least, German language does not have an equivalent to the English term *exercise*. Exercise describes a planned, and structured subset of physical activity aiming at maintaining or improving of physical fitness (Caspersen et al., 1985). In German, terms such as sport or sporting activity are often used to describe these activities. Within the MoMo framework, the term *körperlich-sportliche*

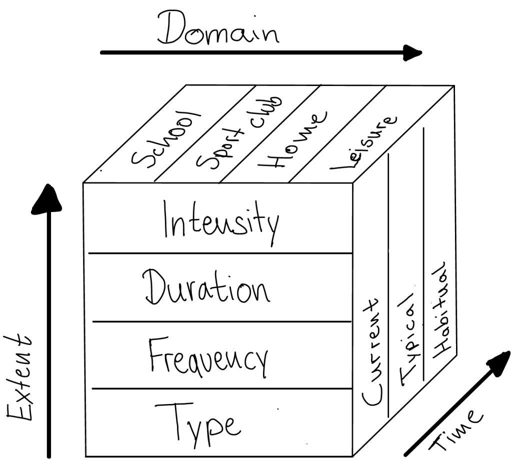


Figure 2.1: Dimensions of PA for surveillance by questionnaire (modified and translated version, cf. Woll, 2006)

Aktivität is used to clarify that all kinds of movement or activity are included (von Haaren-Mack et al., 2023).

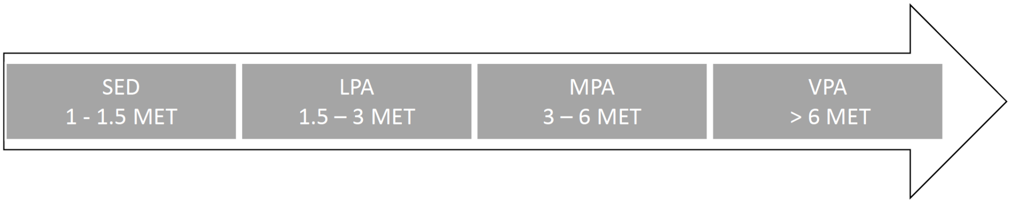
In addition to a clear definition of the object of investigation, it is important to define characteristic properties that can be used to provide a clear description.

2.1.1.1 Dimensions and domains of physical activity

The duration, the frequency, the intensity, and the type or mode of activity are the so-called dimensions of physical activity, and they are often used to describe the physical activity behavior of a subject. For some research questions, the domain or context of physical activity also plays a role. The following section clarifies those terms and illustrate them using examples of everyday task or sport activities.

Duration

The duration reflects the total amount of time that was spent in a certain activity. For example, how long does it take someone to walk from the house to the bus stop or how long the tennis match lasted.



SED – sedentary behavior; LPA – light physical activity; MPA – moderate physical activity; VPA – vigorous physical activity

Figure 2.2: Visualization of the intensity classification of physical activity based on MET

Frequency

The frequency tells us how often an activity occurs over a period of time. E.g., on how many days a week the person takes the bus and has to walk to the bus stop, or how often somebody plays tennis a week.

Intensity

The intensity can be classified based on the rate of energy consumption. It is usually expressed in metabolic equivalents (MET), with one MET being the amount of oxygen that is consumed at rest, while sitting quietly (Jetté et al., 1990). One MET equals 3.5 ml O^2 per kg body weight per minute. Tasks with an energy consumption of two METs require a double amount of oxygen compared to the base rate, tasks with three METs require three times the amount of O^2, and so on.

Pate et al. (1995) proposed a model to classify physical activity based on the energy expenditure induced by physical activity (PAEE). According to that model, tasks with < 3 METs are classified as light, 3-6 METs as moderate, and > 6 METs as vigorous (Pate, 1995). Later, the category light had been differentiated into sedentary behavior ($\geq 1 - 1.5$ METs), and light physical activity ($\geq 1.5 - < 3$METs)(Rütten and Pfeifer, 2017).

Sedentary behavior refers to any activity in a sitting, lying, or reclining posture while awake that does not lead to an energy expenditure over 1.5 METs (Tremblay et al., 2017).

Light intensity physical activity (LIPA) comprises all activities with an energy expenditure below 3 METs. In most cases, this is not perceived as strenuous. Most of the activities that are necessary to cope with the everyday life fall into this category. Rütten et al. (2017) are talking about basic activity here.

Moderate intensity physical activity (MPA) stands for activities with a PAEE greater than 3 METs that are perceived as a bit strenuous. There is a slight to moderate increase in heart rate and respiratory rate linked to MPA.

Vigorous intensity physical activity (VPA) are activities with a PAEE of 6 METs or more. Those activities lead to a strong increase in heart rate and heavy breathing. They are perceived as very strenuous, and consistent talking is no longer possible.

When walking, for example, intensity is usually related to speed, but other factors such as additional stress from carrying loads can also influence intensity.

Type or mode of activity

Mode of physical activity is the specific activity that is performed. There are lots of different modes of physical activity (e.g., playing hide and seek, doing chores, or PA at the workplace). It is a lot easier to determine the type of activity in the area of club sport, or leisure time sport. Here, the kind of sport is also the mode of activity. Mode of physical activity can also reflect the bio mechanical demands of the activity (e.g. aerobic activity, strength training).

Context

The context describes the circumstances under which the physical activity is performed. This can also include a purpose, or an aim of the activity. Common physical activity contexts are the workplace, in the household, for transportation, or recreational.

2.1.1.2 Measuring physical activity

Over time, a variety of methods to measure PA have been developed and established. Each method has its specific advantages and disadvantages, which must be weighed against each other in advance of each study with regard to the question to be investigated and the target group of the respective study. Basically, the methods can be divided into two categories: The device-supported and standardized methods on the one hand and the self-report or third-party information on the other. Device-based or standardized assessment includes all methods using either a standardized protocol, one or multiple devices (e.g., pedometer, heart rate monitor) to capture the variable of interest, or a combination of both. On the one hand, these are observations carried out as direct observation or by means of recordings, on the other hand, the use of any measuring devices - from relatively simple applications such as pedometers to the complex methods such as respiratory gas analyses or the use of doubly labeled water - fall into this area. The category *Self- or proxy-reports of PA* consists mainly of questionnaires and diaries filled in by the subject himself or by a third party. In case of PA research with children and adolescents, examples for those third parties are usually parents or teachers of the investigated.

Based on the definition of Caspersen et al. physical activity always leads to an increase in energy expenditure. So this is the basic idea to quantify physical activity. With all biochemical processes within the human body producing heat, the most precise method to measure the energy consumption is to measure the produced heat of the individual. To do so, calorimetry is conducted in an isolated, hermetic chamber. This method bears high instrumental costs, and although it gives a very precise measure of the overall energy consumption, it is not applicable to map changing intensities such as varying activities or different movements.

In addition, the metabolism also needs oxygen (O_2) and produces carbon dioxide (CO_2) to generate energy. The oxygen consumption is proportional to the energy consumption and so the energy consumption can be measured indirectly via gas analysis. The spiroergometry is less expensive as the calorimetry and as there are already portable devices it is applicable to a wider range of activities. But, the strength of spiroergometry also lays in measuring the overall energy expenditure. Therefore, it is not qualified to capture activities of daily life in high definition as it rather gives an overall estimate of the energy consumption than a protocol of different intensities over time.

Another method to estimate energy expenditure is the use of stable isotopes which are harmless to health to track metabolic products such as CO_2. A well known example of this type of methods is the doubly labelled water method (DLW), that has become the gold standard for total energy consumption in daily life (Westerterp, 2017). A subject is given a certain amount of doubly labelled water ($^2H_2{}^{18}O$) to enrich the subject body water with heavy hydrogen (^2H) and heavy oxygen (^{18}O) (Westerterp, 2017). Then the difference in washout kinetics between both isotopes is determined via blood-, saliva-, or urine samples (Westerterp, 2017). The difference between the isotopes is a function of carbon dioxide production, and so an estimate of energy expenditure. As you only need blood-, saliva-, or urine samples at the start and end of the investigation period the DLW is appropriate to capture energy expenditure in any environment, and without any kind of interference between the measurement and the behavior of the subject (Westerterp, 2017). DLW as a form of indirect calorimetry has the same disadvantages as the other methods of this family. It's very accurate in estimating total energy consumption, but also unable to capture short-term increases of energy expenditure due to physical activity. Moreover, the used isotopes and even more the laboratory equipment are expensive, and trained personal is needed to analyze the blood-, saliva-, or urine samples.

In addition to the methods above, which quantify energy expenditure either by measuring the heat produced by the body or by estimating the energy expenditure based on oxygen consumption or carbon dioxide production, there are several methods that estimate the energy expenditure based on an indicator that is not directly related to the energy production process. Common indicators used are the heart rate, steps over time, or acceleration signals. Each of those indicators, or more precisely the methods used to capture the indicator have their specific pros and cons.

A common method is to estimate the energy consumption based on the heart rate. Since the development of small wrist-worn monitors, that are wireless connected to the chest strap with the electrodes, and that are able to store high resolution data over days, the practicality and feasibility of this method has immensely improved (Strath et al., 2013). Basically, the heart rate responses to cardiorespiratory load, and while the relation between O_2-consumption and heart rate is mostly linear it is a reliable estimate for the energy expenditure (Strath et al., 2000). The estimate is even more precise if the individual relation between heart rate and O_2-consumption is determined via spiroergometry. One problem of the use of the heart rate is in low-intensity levels of PA, as heart rate can also be influenced by environmental factors (e.g. temperature, humidity), emotional state (e.g., fear, excitement, anger), or other factors that cause sympathetic reactivity (e.g. caffeine consumption) (Strath et al., 2000; Strath et al., 2013). Although, heart rate shows relatively strong correlation with the intensity of movement especially during moderate to high intensive aerobic exercises (Strath et al., 2000; Strath et al., 2013), the heart rate response lags regarding the onset of PA and the energy demands (Strath et al., 2013). As a result of this lag period, heart rate monitoring may miss sporadic PA events, and tends to overestimate time spent in different intensities while recovery (Strath et al., 2013). After all, heart rate can be a moderate, or if calibrated on the subject strong predictor of EE (Strath et al., 2000; Strath et al., 2013). Typical measurements derived from heart rate monitoring are the time spent in different levels of activity, and total PAEE. As heart rate monitors are easy to apply and do not affect the subject, the method can be used either individually or in addition to other assessment methods (e.g., accelerometer, questionnaires) in free-living studies. If calibration is necessary or wanted, the potential number of subjects is determined by the timely and personnel resources of the study.

Another assessment method is the use of motion sensors, mainly accelerometers or pedometers. The second ones are typically belt- or waistband-worn sensors that detect steps. Therefore, when using pedometers, PA is expressed in steps over time or total number of steps. There are different mechanisms used in pedometers to detect steps. The original mechanism is a elastic beam with an mass at the end that responses to the displacement of the hip while walking. The movement of the beam opens and closes an electric circuit and by that produces a signal that is counted (Crouter et al., 2003; Müller et al., 2010). A second type of pedometers use a magnetic switch triggered by the induced movement to generate the signal that is counted (Crouter et al., 2003; Müller et al., 2010). The third pedometer type is a basic accelerometer that consists of an elastic beam and a piezoelectric crystal (Crouter et al., 2003; Müller et al., 2010). For all types, if the impulse of the movement is sufficient to activate the mechanism, a signal is generated and the step is counted. If the impulse is not sufficient, for example at very low movement speed, the mechanism is not triggered and the step is not recorded. As a result, pedometer tend to underestimate steps taken at low walking speed (Bassett et al., 1996; Crouter et al., 2003; Müller et al., 2010). Modern pedometers often provide additional information, e.g. distance traveled, or kilo-calories burned. Those metrics are calculated based on the measured steps and therefore less precise (Müller et al., 2010). Pedometer reach their limits when the activity to be investigated does not cause a significant displacement of the sensor at the hip and so they do not result in a measurable signal, e.g. riding a bike, rowing, or swimming (Müller et al., 2010). Those activities are not characterized by steps, and therefore pedometer are not suitable to capture those forms of physical activity.

As the name suggests, accelerometer sensors capture the acceleration of the body during movement. EE can be calculated based on the acceleration values, and on top of that duration, intensity, and frequency of physical movement can be derived from the signal (Chen and Bassett, 2005; Müller et al., 2010; Strath et al., 2013). There are uni-, bi-, and tri-axial accelerometer sensors available, that capture acceleration in one plane (usually vertical plane), two planes, or three planes respectively (Chen and Bassett, 2005; Müller et al., 2010; Strath et al., 2013; Westerterp and Plasqui, 2004). The sensor can be attached to the subject with an elastic belt or stuck directly onto the skin with a patch. Typical sensor positions are hip, ankle, wrist, lower back, or thigh (Chen and Bassett, 2005; Strath et al., 2013). The sensor also can be inserted into a commonly used device (e.g. smartphone). Due to technological advances, sensors have become smaller and lighter over the years, while battery life and storage capacity have continued to improve. Because of this and the associated low restriction of the subject by the device in everyday life, these devices have been used very frequently for some time (Strath et al., 2013). The acceleration signal is usually processed as *counts* which is a unit-free device-specific value. Via calibration of the accelerometer these counts are either translated into energy expenditure units (ie, METs or kilocalories (kcal)), or used to define thresholds to classify the PA into intensity categories (Chen and Bassett, 2005; Strath et al., 2013). In this way, the accelerometer values can be converted, e.g. into kcal per time or it can be determined how much time a person was active in which intensity range. The latter can be used to check whether a subject or a population meets a recommendation like at least 60 minutes PA of moderate to vigorous intensity per day. However, different approaches to the development of the equations or different calibration studies lead to a variety of algorithms. In addition, these algorithms depend on the sensor used as well as on the wearing position and the activities used for calibration, which makes comparability difficult (Strath et al., 2013).

Last but not least, the PA can be assessed via subjective methods. Basically, there are two different forms of subjective methods to assess physical activity: questionnaires (PA questionnaire (PAQ)) and PA diaries/logs (Müller et al., 2010; Strath et al., 2013; Westerterp, 2013). The great advantage of this type of recording is the low cost associated with it. This makes these methods very suitable for large studies, such as population-based surveys (Dollman et al., 2009; Müller et al., 2010). PAQs can be divided into three groups: global, recall, or quantitative history (Strath et al., 2013). Global PAQs are short questionnaires that give a quick overview of a subjects general PA. They are often used for classification (e.g. activity status) or to check whether a subject reaches a given threshold meets a recommendation (e.g., 150 minutes MVPA per week) (Strath et al., 2013). Short recall questionnaires can give a quick overview of a subjects PA, and are often used in epidemiological studies to assess the adherence to guidelines and recommendations (Strath et al., 2013). The International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003) is an example of a short recall questionnaire. The third category contains detailed questionnaires on the extent and intensity of PA in the past. They are usually conducted by an interviewer and refer to a defined period of the past (e.g., last month, last year, lifetime) (Strath et al., 2013). They are longer than global or short recall questionnaires and they are used to understand what types and intensities of PA contribute to mortality (Strath et al., 2013). An commonly used example is the Bone Loading History Questionnaire (Dolan et al., 2006), which recalls the hip and spine weight-bearing and bone-loading activities from childhood to the past year (Dolan et al., 2006; Strath et al., 2013).

2.1.1.3 Adherence to physical activity guidelines

While on the one hand the health-promoting effect of physical activity is examined, on the other hand the threat to health through a lack of the same is in focus. Lack of physical activity is often referred to as physical inactivity, or when discussing the health benefits of physical activity, insufficient physical activity is often used. However, this designation requires a reference point. Physical activity is a measurable metric, thereby inactivity would basically be the zero point of the scale. This is not the case in practice, as it would also exclude any change in the position of the body. It is therefore necessary to define an alternative threshold value that is greater than zero to distinguish between sufficient levels of physical activity and insufficient levels, or between physical activity and physical inactivity. A common practice is to use physical activity recommendations as cutoffs for classification, e.g., an average of 60 min of MVPA per day (WHO) in children and adolescents. Individuals who achieve 60 min or more per day are classified as physically active, those who do not achieve the threshold are considered inactive. Therefore, physical inactivity or lack of physical activity in general can be understood as the failure to achieve a recommended or set level of physical activity, rather than the complete absence of it.

The moment a distinction is made between physical activity and physical inactivity, physical activity becomes a dichotomous or, if there is more than one active group (e.g., active and highly active), categorical quantity. Physical inactivity is always just the one category that groups together those who do not meet the criterion (e.g., 60 min of MVPA per day). When the threshold of 60 minutes of MVPA per day is used to classify, it typically does not differentiate whether the person achieves 10 minutes or 58 minutes of MVPA per day, both are considered inactive because inactivity is no longer a metric.

In this work, the 60-minute MVPA per day threshold mentioned above is primarily used for classification purposes. If a different threshold is used, it will be clearly stated.

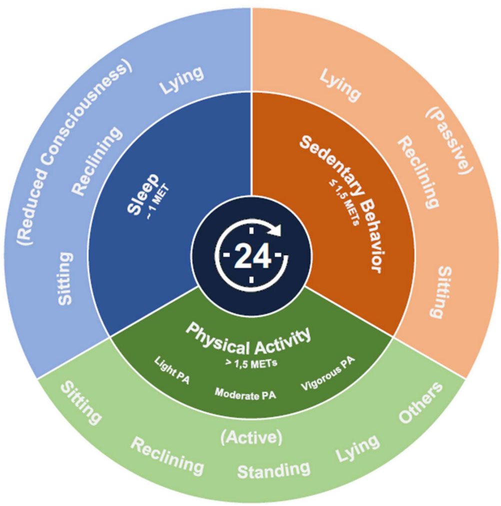


Figure 2.3: The 24h physical behavior cycle to categorize physical behavior based on energy expenditure, posture, and state of consciousness

2.1.1.4 Future research perspective

Both, PA and sleep have been recognized as important contributors to human health. The accumulated evidence on the health benefits of optimal sleep or MVPA patterns led in specific recommendations for those activities (Rosenberger et al., 2019). The situation is less clear regarding the effects of sedentary behavior or low-intensity physical activity. Therefore, only general and nonspecific recommendations have been made for these activities to date (Rosenberger et al., 2019). So far, the recommendations deal with each of the behaviors separately, usually looking only at the time spent on one of the activities during the day. Possible interactions between the effects on health have been neglected so far. However, there is evidence that time spent on one of the activities may influence or alter the effect of the others on health (Rosenberger et al., 2019; Tremblay et al., 2017). Therefore, a wholistic approach that considers all behavioral patterns as proposed in the 24h physical behavior cycle (cf. fig. 2.3) is important. Here, the day is considered as a whole and divided among the three behaviors, sleep, sedentary behavior, and physical activity. The focus is no longer on the individual activities and their effects, but on the combination of all aspects and their interactions (Tremblay et al., 2017).

2.1.2 Health

„Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.“(WHO, 1946 as cited in Franke, 2006)
The definition of the WHO that was first published in 1946 is one of the most popular, and also most discussed and criticized. In this definition health is characterized by four features (Blättner and Waller, 2011): (1) Health is defined positive and as the endpoint of a continuum, (2) health is defined as final state, (3) health is defined as subjective evaluation, and (4) health is defined multidimensional (physical, mental, social).

Another point of view is to define health itself not as a natural state, but rather as a process or an interaction of various factors and their interpretation. Independent from whether health is seen as a state or a process, but depending on background and context, numerous, sometimes contradictory approaches are available to explain health from different perspectives, with the definition of the WHO being one of them.

Another common viewpoint is the classical medical view, which sees health as the opposite of disease. Other approaches focus on individual well-being or coping with everyday life. Some see health as balance, others see it as an ongoing adaption to environmental influence. Last but not least, there is the view that health means conforming to the norm.

The following section discusses the different understandings of health in more detail. Franke (2006) chooses the term dimension here and states that it is not about an evaluation in the sense of right and wrong, but about a classification and grouping of the different concepts in order to approach the complex construct of health in this way (Franke, 2006).

2.1.2.1 The pathogenic view: health as the absence of disease

The understanding of health as freedom from disturbance or the absence of diagnoses is therefore generally referred to as a negative definition, since health is defined here in terms of the absence of disease (Blättner and Waller, 2011; Franke, 2006). This view is not only one of the oldest views of health, but also forms the basis of Western medicine. Health is compared with statistical norms and criteria that are set and reviewed by experts. Those who meet the criteria or whose scores are within the norms are considered healthy, if the values are exceeded or fallen short of, one is sick. From this point of view, health and disease are mutually exclusive, since health ceases the moment a disease is detected. Health and disease are, so to speak, the two manifestations of a dichotomous distribution. Belonging to one of the categories is determined by the presence, or absence, of a diagnosis.

A fundamental challenge of this approach is to define the norms or thresholds that distinguish disease from health. Furthermore, the negative definition of health has been criticized as too narrow, especially by the health and social sciences. The core of the criticism is the lack of consideration of the subjective condition of the persons concerned in the evaluation of health (Franke, 2006).

2.1.2.2 Health as well-being

In contrast to the pathogenic viewpoint, where health is defined by the absence of disease, this view focuses on subjective feelings. Health is understood as well-being, which goes beyond the mere absence of physical or mental impairments (Blättner and Waller, 2011; Franke, 2006). The most prominent representative of this category is the WHO definition cited at the beginning of the section. The WHO definition has been repeatedly attacked and criticized since its publication, among other things for the fact that the state of complete well-being is factually unattainable (Blättner and Waller, 2011; Franke, 2006). At the same time, it is the definition on which the largest group of experts has been able to agree so far. Moreover, in a jungle of national health policies, the definition fulfills the function of an overarching goal to which all can subordinate themselves. A goal that cannot be achieved in principle, but for this very reason should be striven for in its best possible form (Blättner and Waller, 2011). The preamble to the 1946 WHO Constitution declares the possession of the best possible state of health to be the fundamental right of every human being, irrespective of race, religion, political opinion, or economic and social status (Blättner and Waller, 2011).

2.1.2.3 Health as performance

While the dimensions of health presented so far refer to the states and experience of body and mind, the concept of health as performance is more linked to functional aspects. Health is measured by how well someone is able to fulfill his or her task or role in society (Franke, 2006). A key aspect of performance from society's perspective is the ability to work. Therefore, healthy is often equated with able to work. At the same time, the assessment of health is based on the fulfillment of the tasks assigned to a person or intended for the person by society. This ultimately means that there is no such thing as health, but that health is always an individual assessment of the extent to which a person fulfills his or her (social) role (Franke, 2006).

2.1.2.4 Health as homeostasis

Health as balance is similar to the pathogenic understanding of health, a very old and widely used concept (Franke, 2006). Examples of this view can be found, among others, in Hippocrates, for whom a person was healthy when there was a balance between the four humors (blood, black bile, yellow bile, phlegm) (Franke, 2006; van Spijk, 2011). Balance theories such as Yin-Yang or Ayurveda are also found in Eastern medicine (Franke, 2006). Depending on the time when a model was formulated and the related level of knowledge of society, homeostasis refers to different systems. In modern models, the main emphasis is on the balance between the individual and society, and between somatic and psychological factors. In the psychoanalytic model of Freud, the balance of the three instances of the psychic apparatus, represents for him the basis of mental health (Franke, 2006). The commonality of so called homeostasis models is that a person is considered healthy if he or she is in a balanced state. Changes in the person or their environment pose threats to this state and endanger health. An important aspect of health in the homeostasis model is the ability to restore the state of equilibrium as quickly as possible after such an attack.

2.1.2.5 Health as heterostasis

In contrast to the idea of homeostasis, which focuses on maintaining or returning to a state of equilibrium, adaptation to change and evolution is the core of heterostasis models (Franke, 2006). Thus, health is not the absence of disease, but the defense and resistance to risk factors and disease states that are integral to the models (Franke, 2006). The question of what keeps the organism healthy despite adverse conditions leads to one of the best known representatives of the group of heterostasis models, the salutogenesis model of the Israeli medical sociologist Antonovsky. Two assumptions underlie the salutogenesis model. First, it sees illness as a normal aspect of human life, and second, it sees illness and health as poles of a common continuum (Franke, 2006). Antonovsky refers to the end point of the continuum as "health-ease" and "dis-ease" and therefore speaks of the HEDE continuum (Franke, 2006). Unlike other research approaches, salutogenetic research focuses on people making it as close as possible to the health pole on the HEDE continuum. The HEDE continuum is multidimensional and a person's position on the continuum is determined by both objective and subjective factors.

2.1.2.6 Health in a biopsychosocial perspective

The biopsychosocial model is probably the most widely used theoretical approach today to explain the relationship between body and soul or brain and mind (Egger, 2015; Goodman, 1991). The biopsychosocial model developed from studies in general systems theory and its application to biology (Egger, 2015). The model aims to provide a holistic understanding of health and disease. To this end, the model combines the biomedical, psychological and socio-ecological dimensions of health and disease into an integrated, dynamic and hierarchically organized overall understanding (Egger, 2015). The aim is not just to create an additive list of biological, psychological and socio-ecological factors that play a role in the context of health and illness, but rather to develop a verifiable, scientific and theoretical basis for these aspects in a holistic approach (Egger, 2015).

Since health as a whole is not tangible, it naturally makes sense to proceed dimensionally in the detailed resolution. The involved sections of reality with their recognizable factors can be named individually and then integrated into a holistic system (Egger, 2015).
How to link the two constructs of physical activity and health is the topic of the next section.

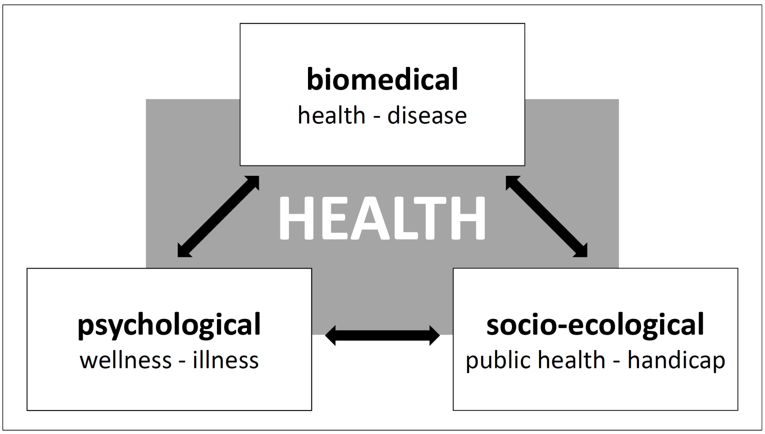


Figure 2.4: The three dimensions of health and disease within the biopsychosocial model (own representation based on Egger (2015))

2.1.3 The link between physical activity and health

Linking physical activity and health requires a model. Such a model can be found, for example, in Bouchard.

The Bouchard model shows how physical activity, health-related fitness and health are interrelated (Bouchard et al., 2012). It also takes into account the influence of genetic predisposition and other influencing factors. The model assumes a reciprocal relationship between physical activity and health, i.e. physical activity has an effect on health and health in turn influences activity. Health-related fitness represents an indirect link between physical activity and health. Physical activity influences fitness, which in turn affects health. The model thus assumes that physical activity can affect health in two ways: directly and indirectly. According to the model, genetic predisposition influences both the constructs themselves and the relationships between the constructs. The model also assumes that there are other factors that influence physical activity, health-related fitness and health. These factors may be habits, individual characteristics or the person's social or physical environment.

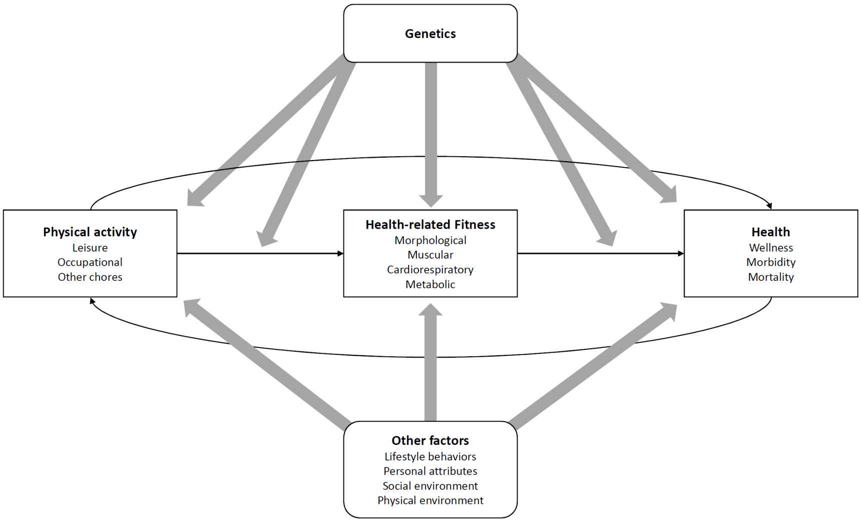


Figure 2.5: The relationship between physical activity, fitness and health (own representation based on Bouchard et al., 2012))

Another factor that plays an important role in the connection between physical activity and health is time. Figure 2.6 shows a model by Hallal et al. (2006) that illustrates possible ways in which physical activity can affect health and includes this factor (Hallal et al., 2006).

The model by Hallal et al. (2006) proposes several mechanisms by which adolescent physical

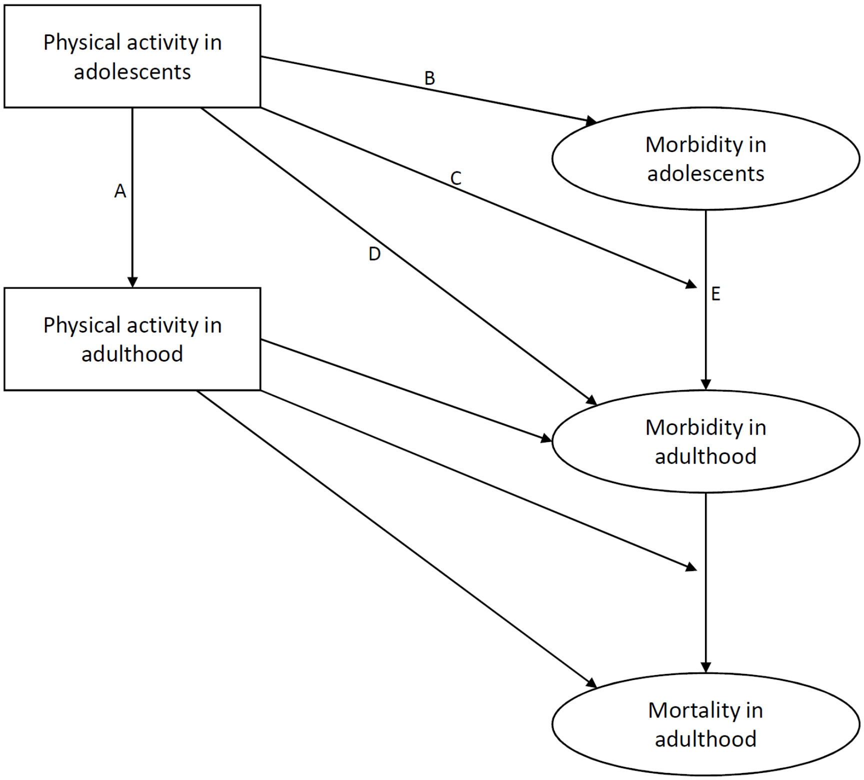


Figure 2.6: The possible pathways between physical activity and health from adolescents to adulthood according to Hallal et al. (2006)

activity affects health simultaneously and in later life. These mechanisms include both direct and indirect effects. The direct effects (pathways A-D) are most relevant to the topic of the dissertation. The indirect effect (pathway E) suggests an effect of current health on future health, a mechanism that is referred to as tracking. The direct effect in pathway A is also a tracking effect. Physical activity in adolescence carries over into adulthood, influencing future health. The other mechanisms are based on the direct effects of physical activity on adolescent morbidity (pathway B), on the treatment and prognosis of adolescent morbidity (pathway C), and on adult morbidity (pathway D) (Hallal et al., 2006).

In the following work, the model proposed by Bouchard is used as basis. Starting with the model, the focus will be on various parts of the model in the further course of the work. The constructs of physical activity and health have already been outlined in the theoretical part. The next part focuses on the presentation and measurement of health in research in connection with physical activity. Subsequently, data from the MoMo study will be used to present physical activity, physical health and their interrelations.

2.2 Current research on physical activity and health in children and adolescents

The following section takes an in-depth look at the recording and quantification of physical health in the context of activity research with children and adolescents. Figure 2.7 illustrates where the following topic is located in Buchard's model. The core of this section is the paper *Indicators to Assess Physical Health of Children and Adolescents in Activity Research — A Scoping Review*. Slightly modified version of Paper I published on 13th October 2021.

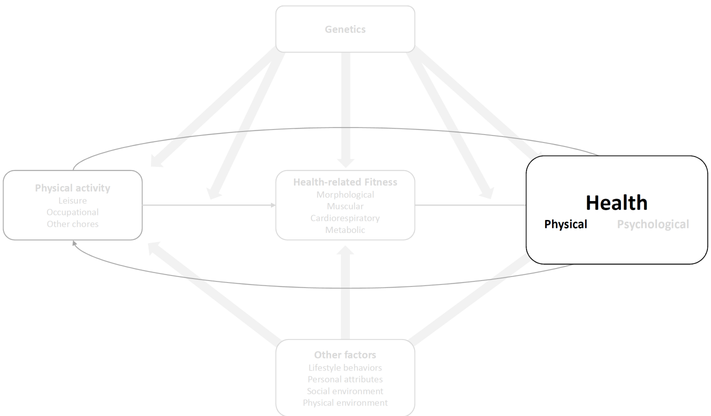


Figure 2.7: Localization of the topic of the section in the model of Bouchard

Indicators to assess physical health of children and adolescents in activity research – a scoping review

Abstract: Sufficient physical activity can help promote and maintain health, while its lack can jeopardize it. Since health and physical activity lay their foundation for later life in childhood and adolescence, it is important to examine this relationship from the beginning. Therefore, this scoping review aims to provide an overview of physical health indicators in children and adolescents in research on the effects of physical activity and sedentary behavior. We identified the indicators used to quantify or assess physical health and summarized the methods used to measure these indicators. We systematically searched Scopus, Pubmed, and Web of Science databases for systematic reviews. The search yielded 4,595 records from which 32 records were included in the review. The measurements for physical health reported in the reviews contained measures of body composition, cardiometabolic biomarkers, physical fitness, harm/injury, or bone health. Body composition was the most used indicator to assess and evaluate physical health in children, whereas information on harm and injury was barely available. In future research longitudinal studies are mandatory to focus on the prospective relationships between physical activity or sedentary behavior, and physical health.

Keywords: body composition; cardiometabolic biomarkers; physical fitness; youth; physical activity; sedentary behavior

Introduction

Physical inactivity is one of the leading risk factors for all-cause mortality reported by the World Health Organization (WHO) (World Health Organization, 2009). Four of the other top 10 factors are related to physical activity (PA) as well. Together those five factors (high blood pressure, high blood glucose, overweight and obesity, physical inactivity, and high blood cholesterol) were accountable for 19.5 million deaths worldwide in 2004 (World Health Organization, 2009).

The leading risk factor is hypertension and is the most common risk factor for cardiovascular diseases (CVD). Strong evidence demonstrates that PA reduces blood pressure (BP) among adults with normal BP, pre-hypertension, and hypertension, which makes PA suitable to prevent hypertension as well as treat it (Pescatello et al., 2019). Additionally, PA seems to be appropriate to reduce high cholesterol. Poitras et al. (Poitras et al., 2016) reported favorable associations of total PA with total cholesterol and MVPA with non-HDL cholesterol.

Moreover, PA could be an effective way to reduce blood glucose levels: A theoretical approach by Hansen et al. (Hansen et al., 2018) showed that reallocating time from sedentary behavior (SED) to moderate-to-vigorous physical activity (MVPA) would lead to reduced glucose levels in adolescents. In addition, PA interventions showed effectiveness in reducing HbA1c levels in non-diabetic populations (Cavero-Redondo et al., 2018). With clustered cardiometabolic risk showing stability from childhood to adulthood (Camhi & Katzmarzyk, 2010), monitoring and prevention needs to start early.

Overweight and obesity are also not only a leading risk factor in the adult population. As overweight and obesity in childhood are associated with a greater risk of chronic diseases such as

type 2 diabetes in later life (Abarca-Gómez et al., 2017), they are already a problem in children. While it is difficult to lose weight or to maintain healthy weight after weight loss ((MacLean et al., 2015)), it is important to prevent excessive weight gain in childhood and adolescents. Data from the International Children's Accelerometer Database (ICAD) showed associations between MVPA and lower body mass index (BMI) and waist circumference (WC) z-scores. Those associations were stronger at the higher percentiles, suggesting that increasing MVPA could help to lower the number of children and adolescents at the upper tail of BMI and WC frequency distributions (Mitchell et al., 2017). Considering that overweight and obese children often become overweight and obese adults (Herman et al., 2009), early countermeasures are necessary.
The lack of physical activity in school-aged children is already associated with adverse physical health outcomes and reduced physical fitness (Janssen & Leblanc, 2010; Poitras et al., 2016). On top of that, PA in childhood seems to predict PA levels in later life (Telama et al., 2005, 2014). As mentioned above, clustered cardiometabolic risk showed stability from childhood into adulthood (Camhi & Katzmarzyk, 2010) and similar findings are available for obesity (Herman et al., 2009). This suggests that health status during childhood directly affects the adult health status.
Against this background, it should be in the general interest to educate healthy and active children who will grow into healthy and active adults to tackle those issues. Therefore, this scoping review aimed to provide an overview of physical health indicators in children and adolescents in research on the effects of PA and SED. The aim was to identify the indicators used to quantify or assess physical health and summarize the methods used to record these indicators. This review is intended to serve as a basis for planning studies for future research, thus contributing to further analysis of the effects of PA and SED on physical health of children and adolescents.

Materials and methods

Although, we conducted a scoping study, we adopted the methods of a systematic review regarding literature search, inclusion/exclusion of literature, and data collection as proposed in the PRISMA statement (Moher et al., 2009). Eligibility criteria were defined a priori to ensure consistency in decision-making.

Eligibility Criteria

The PICOS framework (Schardt et al., 2007) was used as an orientation to define eligibility criteria and to ease the searching process. We used the following criteria for the inclusion: (a) To identify the most important indicators used in the field, the scoping review focused on systematic reviews

(SR) and meta-analyses; (b)We evaluated SRs on healthy children and adolescents aged 6 to 17 years. To get a preferably realistic result, participants with special conditions (e.g., disabilities or chronic diseases) were no reason for exclusion as long as they were part of cross-sectional samples. Whereas studies entirely focusing on participants with special conditions were excluded; (c) All forms of PA or lack of PA with reported effects on physical health were considered. Sedentary behavior (SED) is defined as waking behavior with an energy expenditure equal to or less than 1.5 metabolic equivalents (METs) (Tremblay et al., 2017). Therefore, it can be judged as a form of activity with low intensity, and SRs conducted on SED as exposure were considered eligible; (d) A control group was not applicable due to the focus on SRs; and (e) As this scoping review aims to identify the indicators to assess physical health, the included SRs must at least include one aspect of physical health.

Information sources and search

PubMed (1946–May 2020), Scopus (1960–May 2020), andWeb of Sciences (Core Collection, 1945–May 2020) were used to identify relevant articles. Additionally, the Cochrane Library was checked for relevant entries. The references of the records were checked as well for additional relevant citations. The search terms consisted of variations and combinations of the keywords "physical activity", "children", and "health". The full search is available upon request. The search was limited to results published in English or German.

Study selection

Citations were downloaded into a reference management software (Citavi 6.5, Swiss Academic Software GmbH, Wädenswil, Switzerland) and duplicates were removed automatically. Two reviewers (S.K., A.B.) screened the title and abstract of the remaining references. An agreement was essential for exclusion at this level. Full texts were then screened against the eligibility criteria by two reviewers (S.K., A.B.) and agreement was required for inclusion in the review. If agreement at any level could not be reached through discussion a third reviewer (C.N.) was contacted and a decision was made by majority vote.

Data collection and items

The data-extraction form was created by the first author and reviewed by the other authors. Each record was assigned a unique identifier. Extraction was completed in Excel (Microsoft

Corp., Redmond, WA, USA) by one reviewer (S.K.) and checked for accuracy by another (A.B.). Characteristics of the SR (author, title, year of publication, number of studies in the SR/MA, an age range covered), characteristics of the PA or SED measurement, information if a meta-analysis was conducted with several included studies, and health indicators, as well as measurements used to assess those indicators, were extracted. Reviewers were not blinded to the authors or journals when extracting data. The data-extraction form is available upon request by the corresponding author.

Synthesis of results

The results were grouped by the reported exposure and structured around the reported health indicators representing physical health and are presented as a narrative synthesis.

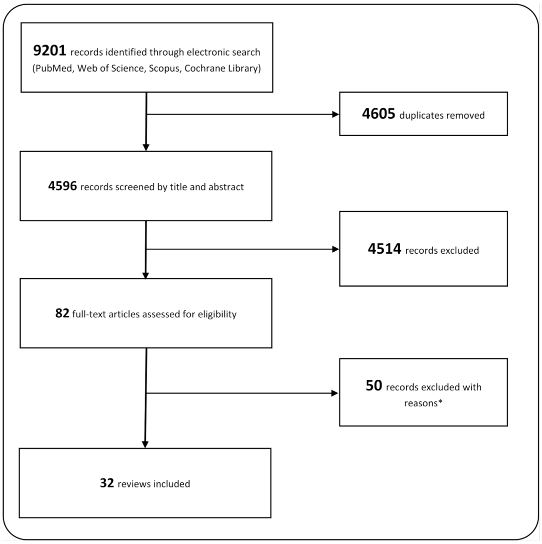


Figure 2.8: Flow-chart literature search and study selection process *Reasons for exclusion:no systematic review (e.g., conference paper, mini review . . . ; 26), no physical health indicator (4), no PA or SED measure (4), special population (2), wrong age (4), missing information (3), and wrong focus, e.g., comparison of training effects (7).

Results

Electronic search

The systematic literature search, as presented in Figure 2.8, was conducted according to the PRISMA guidelines. The search yielded 9,201 records. After the removal of duplicates, 4,595 records remained and 4,513 were excluded after screening titles and abstracts. The remaining 82 records were assessed for eligibility and 50 records were excluded with reasons. A full list of the reasons for exclusion is available upon request. Thus, 32 records remain for inclusion in the analysis.

Study characteristics

According to the inclusion criteria, systematic reviews and meta-analysis were suitable for inclusion. Since this scoping review is aimed at the indicators used, it is of secondary importance whether the source is a systematic review or a meta-analysis. Therefore, to enhance the readability of the manuscript SR refers to both in the further course.
Tables 1–3 present the characteristics of the 32 SR stratified by the exposure of the included studies. Seventeen of the identified reviews focused on PA as exposure, eleven focused on SED, and four SRs included studies focused on PA as well as studies focused on SED.
The number of included studies for the SRs ranged from eight to 235. Twenty-one SR included ten to 50 studies, three SR included less than ten studies, three SR included 50 to 100 studies, and four SR included more than 100 studies.

Table 2.1: Characteristics of the included reviews including studies on effects of PA.

Reference	# Studies	Exposure	Outcome
Gao et al., 2015	35	Active video games	Health outcomes
Gomez-Bruton et al., 2013	23	Swimming	Bone tissue
Gomez-Bruton et al., 2016	14	Swimming	Bone mineral density
Guinhouya et al., 2011	37	PA	Metabolic syndrome, insulin resistance
Henriques-Neto et al., 2020	11	Active commuting	Physical fitness
Krahnebühl et al., 2018	21	PA	Bone geometry
Lubans et al., 2011	27	Active travel	Health-related fitness
Miguel-Berges et al., 2017	36	PA	Adiposity
Poitras et al., 2016	162	PA	Health indicators
Ramires et al., 2015	18	PA, inactivity	Body fat, obesity
Rauner et al., 2013	14	PA,PF	Overweight
Saunders et al., 2013	8	Active travel	Health benefits
Sitthipornvorakul et al., 2010	13	PA	Neck pain, low back pain
Tan et al., 2014	37	PA	Bone strength
Wilks et al., 2011	14	PA	Obesity
Yang et al., 2020	9	PA, calcium	Bone health
Zulfarina et al., 2016	9	PA	Bone mineral acquisition

Note: # - Number of included studies.

Table 2.2: Characteristics of the included reviews including studies on effects of SED.

Reference	**# Studies**	**Exposure**	**Outcome**
Carson et al., 2016	235	SED	Health indicators
Chinapaw et al., 2011	31	SED	Biomedical health indicators
Cliff et al., 2016	88	SED	Health and development
Fröberg & Raustorp, 2014	45	SED	Cardio-metabolic risk
Koedijk et al., 2014	17	SED	Bone health
Lee & Wong., 2015	24	SED	Blood pressure
Rey-Lopez et al., 2008	71	SED	Obesity
Ribeiro Canabrava et al., 2019	50	SED	Cardiovascular risk
Tanaka et al., 2014	13	SED	Adiposity
Tremblay et al., 2011	232	SED	Health indicators
Van Ekris et al., 2016	109	SED	Biomedical health indicators

Note: # - Number of included studies.

Table 2.3: Characteristics of the included reviews including studies on effects of SED and PA.

Reference	**# Studies**	**Exposure**	**Outcome**
Oliveria & Guedes et al., 2016	18	PA,SED	CRF, Metabolic syndrome
Prentice-Dunn et al., 2012	17	PA,SED	Childhood obesity
Skrede et al., 2018	30	SED, MVPA	Cardio-metabolic risk factors
Verswijveren et al., 2018	29	Activity patterns	Cardio-metabolic risk factors

Note: # - Number of included studies.

Health indicators

The measurements reported in the SRs could be summarized as measurements of body composition (BC), cardiometabolic biomarkers (CMB), physical fitness (PF), harms/injuries (H&I), or bone health (BH).

SR with PA as exposure
Seventeen SR, published between November 2010 and April 2020, evaluating the effects of PA on the physical health of children and adolescents were identified by our search.

Body composition
Ten SR included body composition as an indicator for physical health. Body composition was used as an indicator for physical health in association with active travel/commuting (Henriques-Neto et al., 2020; Lubans et al., 2011; Saunders et al., 2013), active video games (Gao et al., 2015), pedometer-determined (Miguel-Berges et al., 2017), or objective measured PA (Poitras et al., 2016), and PA with no further specifications (Guinhouya et al., 2011; Ramires et al., 2015; Rauner et al., 2013; Wilks et al., 2011). Body mass index (BMI), as well as thickness of skinfolds (SF) or sum of skinfolds (SSF) were reported in at least one study in each of the 10 SR or MA. The second most common variable to assess body composition was waist circumference (WC) which was presented in 8/10 SR or MA. Other measurements used to assess and evaluate body composition reported by the studies in the SR were body-fat percentage (%BF) (6/10), fat mass (FM) (3/10), fat mass index (FMI) (2/10), fat-free mass (FFM) (2/10), and fat-free mass index (FFMI) (2/10).
One SR was conducted on prospective studies [30] and body-weight change or bodyfat percentage change were used in at least one study to evaluate body composition.

Cardiometabolic biomarkers
Cardiometabolic biomarkers were used as an indicator for physical health in four SR. They were investigated in association with active video games (Gao et al., 2015), active travel (Saunders et al., 2013), objective measured PA (Poitras et al., 2016), and PA with no further specifications (Guinhouya et al., 2011). All 4 SR including studies reporting on blood lipids as well as such reporting on insulin resistance or sensitivity. The measured values for the assessment of blood lipid levels included the following: total cholesterol, HDL cholesterol, triglycerides, and more. The homeostasis model of assessment of insulin resistance (HOMA-IR), fasting insulin levels, fasting glucose levels, among others, were used to assess insulin resistance or sensitivity.

Moreover, different blood pressure measurements, inflammatory markers, or properties and functions of the arterial system were used to assess cardiometabolic health. Some of the included studies also used clustered risk factors or metabolic syndrome scores to evaluate cardiometabolic health.

Physical fitness

Five SR used physical fitness as an indicator for physical health. Physical fitness was used in association with active travel respectively commuting (Henriques-Neto et al., 2020; Lubans et al., 2011; Saunders et al., 2013), active video games (Gao et al., 2015), and objectively measured PA (Poitras et al., 2016). All five SR report on cardiorespiratory fitness. 4/5 SR report on muscular fitness and flexibility. One SR reports on balance and one SR includes at least one study on agility and speed.

Harms and injury

Harms and injuries were only addressed in one SR (Sitthipornvorakul et al., 2011) focused on neck and low back pain. Pain was assessed via questionnaire.

Bone health

Bone health was used as an indicator for physical health in seven SR and evaluated in association with objectively measured PA (Poitras et al., 2016), PA without further specifications (Krahenbühl et al., 2018; Tan et al., 2014; Yang et al., 2020; Zulfarina et al., 2016), and swimming (Gomez-Bruton et al., 2013, 2016). Bone mineral density (BMD) was reported by all seven SR. The second most common variable to assess bone health was bone mineral content which was reported in 6/7 SR. Other metrics used to measure bone health include bone age, total skeletal area, bone stress index, bone strength index, strength–strain index, cross-sectional moment of inertia, cortical thickness, or polar moment of inertia.

SR with SED as exposure

Eleven SR published between March 2008 and October 2019 on the effects of SED on the physical health of children and adolescents were identified by our search. None of them reporting on harm and injury as an indicator for physical health.

Body composition

In SR using SED as the exposure body composition was used as an indicator for physical health in 9/11 (Carson et al., 2016; Chinapaw et al., 2011; Cliff et al., 2016; Fröberg & Raustorp, 2014;

Rey-López et al., 2008; Ribeiro Canabrava et al., 2019; Tanaka et al., 2014; Tremblay et al., 2011; van Ekris et al., 2016) identified SR conducted between 2008 and 2019. BMI was the most common method to assess body composition reported in each of the nine SR, followed by WC (8/9), body-fat percentage (6/9), and skinfold thickness respectively sum of skinfolds (6/9). Other metrics to assess and evaluate body composition reported by at least one of the studies included in the SR were fat mass/body fat (5/9), weight-to-height ratio (WHtR) (4/9), fat mass index (2/9), fat-free mass/lean body mass (1/9), lean body mass percentage (1/9), hip circumference (1/9), and waist-to-height ratio (1/9).

Cardiometabolic biomarkers

Seven of the eleven SR (Carson et al., 2016; Chinapaw et al., 2011; Fröberg & Raustorp, 2014; Lee & Wong, 2015; Ribeiro Canabrava et al., 2019; Tremblay et al., 2011; van Ekris et al., 2016) used cardiometabolic biomarkers as an indicator for physical health. Blood pressure was reported in all seven SR as an indicator of cardiometabolic health. Blood lipid scores, including triglycerides, total cholesterol, or HDL cholesterol among others, were reported in five of the seven SR or MA. Measurements of insulin sensitivity respectively resistance or glucose were also reported by five of the SR. Three of the SR include studies using a combination of cardiometabolic risk factors, clustered cardiometabolic risk, or risk of metabolic syndrome to evaluate cardiometabolic health.

Physical fitness

Physical fitness was used as an indicator for physical health in four of the eleven SR on SED (Carson et al., 2016; Chinapaw et al., 2011; Tremblay et al., 2011; van Ekris et al., 2016). All four SR include studies on cardiorespiratory fitness or strength/muscular fitness. In addition, one SR (Carson et al., 2016) included studies on flexibility and power.

Bone health

Three of eleven SR on the effects of SED in children and adolescents included studies on bone health (Chinapaw et al., 2011; Koedijk et al., 2017; van Ekris et al., 2016). Two of those SR (Chinapaw et al., 2011; van Ekris et al., 2016) only report on bone mass as a measurement of bone health. The metrics used in the studies of the third SR (Koedijk et al., 2017) include BMD, BMC, bone architecture, bone strength, stiffness index, and speed of sound as measurements of bone health.

SR with PA and SED as exposure

Our search yielded four results for SR on physical health aspects of children or adolescents that included studies with PA as well as SED as exposure in their analysis (de Oliveira & Guedes, 2016; Prentice-Dunn & Prentice-Dunn, 2012; Skrede et al., 2019; Verswijveren et al., 2018). The four SR were published between May 2012 and January 2019. All of them focused on either body composition, cardiometabolic biomarkers, or both as a health indicator.

Body composition
One SR solely reports on the effects of PA or SED on body composition (Prentice-Dunn & Prentice-Dunn, 2012) while two SR report on body composition and cardiometabolic biomarkers (Skrede et al., 2019; Verswijveren et al., 2018).
BMI and WC were reported by studies of all three SR. 2/3 also report on SF. One SR each report on body-fat percentage and body-fat mass.

Cardiometabolic biomarkers
One SR was conducted on the effects of PA or SED on the metabolic syndrome, while two SR report results for cardiometabolic biomarkers and body composition.
The one SR on the effects of PA or SED on metabolic syndrome only includes studies reporting on clustered risk factors according to the definition of metabolic syndrome.
The two other SR reporting on cardiometabolic biomarkers include studies on blood lipids, blood pressure, or insulin sensitivity resp. resistance. One of them also includes at least one study reporting results for inflammatory markers.

Discussion

This scoping review aimed to provide an overview of physical health indicators in children and adolescents in research on the effects of PA and SED. The aim was to identify the indicators used to quantify or assess physical health and summarize the methods used to record these indicators. We identified body composition, cardiometabolic biomarkers, physical fitness, harm and injury, and bone health as the relevant indicators to assess physical health in research on effects of physical activity or sedentary behavior in school-aged children. These indicators match those proposed within the framework of the evidence update for the Canadian 24 h Movement Guidelines (Poitras et al., 2016). The current search did not reveal further indicators for physical health.
Body composition was analyzed in 22/32 SR. The ability to derive measures of body composition, such as BMI, from easy-to-assess anthropometric variables is possibly one reason for the high prevalence of this health indicator. The most common proxy variable to assess BC was BMI. BMI calculated from objectively assessed height and weight, as well as BMI calculated based on self or proxy reported data, were used. BMI for age or BMI-z-scores was often used to account for

age and sex of the participants. The BMI is often used to divide subjects into groups, e.g., underweight, normal weight, or overweight. It is also used to classify levels of adiposity. Using BMI as a health indicator, some limitations need to be considered. Although being used to measure body fat, BMI is an indirect measurement and it does not account for age, sex, bone structure, fat distribution, or muscle mass (Rothman, 2008). Therefore, it is recommended to use BMI for age to account for sex and age, which is important when analyzing children (Reilly, 2006). A meta-analysis of the diagnostic performance of BMI to identify obesity showed high specificity, but moderate sensitivity in children and adolescents (Javed et al., 2015). Lacking sensitivity leads to misclassification of obese children as non-obese, which leads to missed opportunities for intervention. Moreover, as an indirect measurement, BMI is not a precise predictor of body fat. Assuming a BMI score of $20kg/m^2$, the corresponding body-fat percentage value can range from 5 to 40% (Ellis, 2001). Looked at the other way around, it can be seen that with a body-fat percentage of 20%, the corresponding BMI can be between 15 and 30 kg/m^2 (Ellis, 2001). Nevertheless, there is consistent evidence that a high BMI for age is an accurate measure for a high body-fat content and it could serve as appropriate tool to diagnose overweight and obesity in children (Javed et al., 2015). Therefore, the use of the BMI for age should be seriously considered when examining children.

The second most commonly used method for assessing BC was the measurement of skinfold thickness at one or more predefined locations. Subsequently, the body-fat percentage is calculated by means of a formula, such as the one developed by Slaughter et al. (Slaughter et al., 1988). While skinfolds show a stronger association with body fat than BMI (Freedman et al., 2013), there are some limitations to be considered as well. A study by Kriemler et al. showed that for subjects over the 95th BMI-percentile the skinfolds do not add to the prediction of body fat or the prognostic value of BMI (Kriemler et al., 2010). Moreover, the measurement of skinfolds is error-prone and highly dependent on the observer (Ulijaszek & Kerr, 1999).

Cardiometabolic biomarkers were used in 14/32 SR and to assess physical health. Blood lipid levels are reported in all 14 SR and measures of blood pressure in 13/14 SR. Reported blood lipid levels mostly include triglycerides, total cholesterol, or HDL cholesterol. In addition, there are various ratios of the individual values (e.g., HDL/TC) or additional values such as LDL cholesterol. Laboratory analysis is necessary to determine the blood lipid levels. With laboratory analysis usually leading to higher costs, this can be an explanation why they are not as often used as measurements of body composition in studies with large samples.

Systolic blood pressure, diastolic blood pressure, and mean arterial blood pressure are reported as measurements of blood pressure. Blood pressure is often used to classify the subjects into subjects with hypertension and those without. Auscultatory measurement of BP is recommended by current guidelines for the diagnosis of hypertension in children. This is mainly caused by the fact that available thresholds have been obtained by the auscultatory method. Additionally, BP measurements by auscultatory method and automated electronic method are not necessarily interchangeable (Stergiou et al., 2017). Considering that interchangeability is not necessarily given between BP measurements, caution is needed when analyzing results from different sources.

Physical fitness is expressed through cardiorespiratory or aerobic fitness in all nine SR. Nevertheless, the evaluation is based on different methods including VO^2max levels or performance in 6 min runs or shuttle run tests. Other proxy variables were muscular fitness (3/9), strength (5/9), or flexibility (4/9). Single studies also used speed or agility as a proxy for PF. In the field of physical fitness research, the inconsistency in the recording of PF is a well-known limitation (Lopes et al., 2020). Furthermore, the parameter “physical fitness” as health outcome must be considered cautiously, since studies consider PF to be an independent factor affecting health, rather than a part of health (Blair et al., 2001).

The limited information on the association of PA and harms or injury is striking, but in line with other findings: Poitras et al. (Poitras et al., 2016) could not identify any study on injuries and harms in their review for the update of the Canadian Physical Activity Guidelines for Children and Youth. Although, harms were judged a critical health indicator by their expert panel. Others highlighted the limited number of studies available for health indicators other than anthropometrics as a limitation (van Ekris et al., 2016).

Bone health was used as an indicator in ten SR, seven of which exclusively focused on bone health. A possible explanation may lie within the assessment of the variables for bone health. Specific instruments are needed such as X-ray machines, or ultrasonic devices and their measurements are independent of other variables such as anthropometrics.

Looking at the variables used as proxies for the health indicators, it is striking that on the one hand, there are numerous different variables for the same indicator, e.g., BMI, skinfold measures, body-fat percentage, or fat-free mass to assess body composition. On the other hand, we recognized some widespread proxy for the health indicators used in a broad range of SR and their included studies. The most common proxy measures reported in the reviews were BMI for body composition, blood pressure for cardiometabolic biomarkers, cardiorespiratory/aerobic fitness for physical fitness, and bone mineral content for bone health. Even though those proxy measures are frequently used and reported by numerous studies, it is mandatory to consider the assessment method and protocol to compare the results and effects of different investigations.

Considering the reported relationships between PA and physical health in the reviews, the overall picture supports a positive association between PA and body composition (BC), cardiometabolic biomarkers (CMB), and physical fitness (PF).

Favorable effects on BC were reported for total PA (Poitras et al., 2016), active travel (Lubans et al., 2011; Saunders et al., 2013), and higher levels of walking (Miguel-Berges et al., 2017). In contrast, two SR found whether consistent evidence for a prospective association of BC and MVPA (Skrede et al., 2019) nor an association between objectively measured activity patterns and BC [47]. Other aspects like nutrition respectively energy intake could be a possible explanation for the inconsistent prospective association of MVPA and BC. Verswijveren et al. (2018) report inconsistent evidence, which may be caused by methodological differences. They used summative coding with an a priori criteria to be coded as evidence and report that many analyzed activity patterns did not meet the criteria (Verswijveren et al., 2018). This also applies to the inconsistent effects on CMB and PF found by their review.

One SR (Henriques-Neto et al., 2020) reports ambiguous results for the effect of active travel on PF. This conflicts with the findings of two other SRs (Lubans et al., 2011; Saunders et al., 2013). While most studies found a positive relationship between active travel and PF, the authors felt the need to identify potential influencing factors or mediators to avoid misconceptions. Therefore, they judged the evidence as inconsistent (Henriques-Neto et al., 2020).

As mentioned before, there is a paucity of reviews analyzing harms or injuries as a health indicator. The only SR included in this scoping review had to deal with the limited available evidence.

Due to different research foci, the evaluation of different forms of PA, and the combination of PA with other factors, bone-health outcomes are not comparable across the evaluated SR.

The overall picture regarding the relationships between SED and the indicators for physical health is less consistent and clear compared to PA. A reason could be differences in the assessment of sedentary behavior compared to PA. Common proxy variables for SED are TV viewing or total sedentary time. Using TV viewing as a proxy measure, it is obvious that sitting on a couch and solely watching TV and watching TV while eating some snacks or consuming a sweetened drink or alcohol most likely have different effects on health. Therefore, differences in dietary behavior associated with TV viewing could explain observed differences in various studies. Another problem arises when focusing on the total amount of sedentary time as a proxy. Conflicting results between studies or between participants within a study may be caused by behavioral differences during the non-sedentary periods. A study by Ekelund et al. (Ekelund et al., 2012) found higher levels of MVPA favorable for cardiometabolic risk factors independent of time spent sedentary. We recommend that when conducting studies of the effect of physical activity or sedentary behavior on physical health in children and adolescents, the choice of survey methods for assessing physical health indicators should be critically considered. Even if the cost and effort of the method are a critical point, especially for large studies, reproducibility, error-proneness, and informativeness are important factors that have to be considered when selecting the method to assess physical health parameters. Furthermore, given the different dimensions of health (e.g., physical health, mental health, social health, etc.), we recommend that authors clarify which aspects of health they are addressing in their work. During the literature search for this review, we encountered several articles in which neither the title nor the abstract gave any indication of the aspect of health being studied. This scoping review has some limitations that need to be mentioned. Considering only indicators related to physical health, the reported indicators also do not represent a holistic understanding of health. For a comprehensive examination of the health status, additional information, e.g., on psychological and social aspects, is needed. Since only published papers were included in the review, publication bias may be a case. A strength of this scoping review is the inclusion of PA as well as the lack of PA as exposure. Thus, not only were the health indicators evaluated for which positive effects from PA could be expected, but also those with negative effects from lack of PA. As a result, this scoping review gives an overview of the indicators used to evaluate the effects of PA or lack of PA on physical health in children and adolescents and could serve as guidance for upcoming studies on physical health and PA. Additionally, the studies included in SR have usually already passed a quality assessment, lowering the risk of biased information.

Conclusion

The physical aspects of health in children and adolescents are typically assessed through indicators of body composition, cardiometabolic health, physical fitness, and bone health. Depending on the aspect to be investigated, it is advisable either to combine one exposure (e.g., PA) with several indicators or to investigate the influence of different behavioral patterns on one indicator. Overall, measures of PA show higher associations to health indicators compared to measures of SED among youth. Further research is needed on possible negative consequences of physical activity or inactivity such as injury and harm, as well as on possible prevention of harm or pain through PA. While cross-sectional associations are frequently investigated, more long-term studies are needed to analyze the prospective relationships between physical activity or its lack and the different health indicators. Future research needs to focus on potential influencing factors on those relationships to gain a deeper understanding of how physical activity and sedentary behavior affect the health of children and adolescents.

Based on the results of the review, the first research question of the dissertation was answered. Physical health is typically expressed through measures of body composition, cardiometabolic biomarkers, physical fitness, or bone health. These results are taken into account in the selection of the MoMo results, which are reported below.
The next chapter offers a more in-depth look at the methodology and data of the MoMo study, which forms the basis of the findings presented in Chapter 4.

3 Methods and data

The following chapter focuses on the study's methods and dataset. First, the MoMo study in general is presented, which is the basis of the work and provides the data. It then presents the samples used to illustrate the results in chapter four. The chapter also includes an introduction to the structure and content of the MoMo study dataset. The final section of the chapter discusses the collection of data on physical activity and health in the context of the MoMo study.

3.1 MoMo study overview

3.1.1 Methodology and procedure

As already described, MoMo was designed as a part of KiGGS. The sampling was ensured by the RKI. All children and adolescents were invited to take part in the core survey of KiGGS, after which the sample was divided among the in-depth modules of the survey, e.g. MoMo, Nutrition Module (EsKiMo), Mental Health Module (BELLA), Environmental Module (KUS).

KiGGS, as well as MoMo, are designed in a so-called cohort sequence design. This means that all participants who took part in the survey are invited back for the following survey waves and in addition a new sample is drawn for each survey period. The sampling procedure is described in more detail in the following section.

In KiGGS, extensive examinations (e.g., blood or urine analyses) of health parameters were conducted during the baseline examination (T1), as well as during the second follow-up examination (T3), in addition to interviewing participants. The first follow-up survey (T2) consisted only of a detailed telephone-based interview.

Motor performance was assessed at all measurement time points by the MoMo survey using on-site sport motor test procedures.

In contrast to the first three waves of the survey (T1 to T3), in which the MoMo surveys were conducted in the follow-up of the core survey, the fourth survey wave was conducted without

Figure 3.1: Testsites of the KiGGS and MoMo Survey

KiGGS. Therefore, the collection of health parameters intended or needed for the analyses had to be integrated into the MoMo survey.

Once the study design and relevant general aspects are clear, the following section presents the sampling strategy.

3.1.2 Sampling and test sites

The sample for KiGGS and thus also for MoMo was designed as a register sample. In a two-stage procedure, the study sites were first selected from the totality of political municipalities in Germany. The original number of 150 municipalities was increased by 17 more in the course of the baseline survey, resulting in the total of 167 study sites. The locations of the testsites are shown in fig. 3.1.

In a second step, an age-stratified random sample of residents aged 0-17 was drawn from the population registers of these localities. From the total sample of the core survey, 50% of children and adolescents aged 4-17 were selected to participate in MoMo. Children under 4 years of age were not selected for MoMo, as this age group could only be covered with very elaborate developmental tests, which would not have been feasible within the scope of the study.

The sampling procedure was developed by the RKI in cooperation with the *Zentrum für Umfragen, Methoden und Analysen (ZUMA)* in Mannheim. Until wave 2 (T3), the drawing of the sample was performed at the RKI. For T4 the drawing was performed at the KIT. The 167 study sites from the previous waves were retained at the first level and at the second level a new random sample was drawn from the register of each locality. Participants for the longitudinal sample had to be invited by the RKI for data protection reasons.

The exact distribution of the participants across the waves of the study, who were selected using the procedure described, is presented in the following section.

3.1.3 Sample size over the survey waves

The evolution of the sample over the four waves is shown in table 3.1. The table shows the total number of participants tested per wave as well as the number of the included longitudinal sample (LS). As you need at least two measurements to be part of the LS, there are no LS participants at baseline.

Wave 3 (T4) is a special feature. Here, due to the COVID-19 pandemic and the associated lockdown measures, field testing was discontinued in spring 2020. The survey was later completed using online questionnaires and digital motor skills tests. Because the two parts of Wave 3 are thus not fully comparable, different sample sizes result for the measurement date, depending on the question.

Table 3.1: Number of participants for each survey wave

	T1	T2	T3	T4
total participants	4,528	5,104	6,233	4,175 (784)
of which LS*	-	2,807	2,654	846 (304)

*LS - longitudinal sample: participant with at least two measurements

T4: value in parenthesis represents participants tested after COVID-19 lockdown

3.1.4 Measures and variables in MoMo

MoMo collects both objective data, which are collected by means of standardized test procedures (e.g., motor performance tests) or with the help of sensors (e.g. accelerometer, body composition analyzer), and subjective data, which are obtained via questionnaires (e.g. behaviour) or interviews (e.g. health status). Basically, the data collected in MoMo can be divided into four areas:

1. Motor Performance
2. Physical Activity
3. Health
4. Other Factors

The following section briefly describes the four areas.

3.1.4.1 Motor Performance

The MoMo test battery contains various tasks to test strength, endurance, coordination, speed, and agility. These were selected in such a way that they meet the design principles of test items for recording motor ability. These are the isolation of abilities, the independence from previous coordinative experience, and low practicability. The current form of the test battery contains of the following eleven tasks, listed in the order in which they are tested: reaction time (reaction speed), line tracking (eye-hand coordination), inserting pins (eye-hand coordination), static stand (coordination, static), balancing backwards (coordination in motion), stand and reach (flexibility), standing long jump (lower extremities strength), jumping sideways (coordination under time pressure), push-ups (upper body strength), sit-ups (torso strength), and bike endurance test (endurance).

Since the baseline survey, the motor test battery were conducted by MoMo. All mentioned tasks had been included in all four surveys. The the baseline survey battery also included a vertical jump on a force plate. Due to the high apperative effort and because the results of the test correlated very highly with those of the standing long jump, this task was no longer performed in the subsequent waves of the study.

3.1.4.2 Physical activity

Physical activity was assessed by questionnaire. The questionnaire covers the areas of everyday activity, club sport, non-club sport and school sport. In all areas, the type, frequency, duration, and intensity of activity were queried. The activity questionnaire had been part of MoMo since the baseline survey. However, some questions were added, removed or changed between the individual waves.

Since MoMo Wave 2 (2015-2018), physical activity was additionally recorded using accelerometers. Using the sensors, the participants' activity was recorded over a week. Sensor-based recording of activity is generally more accurate than retrospective self-report and also minimizes e.g. recall bias. On the other hand, the devices do not provide information on the type and context of the activity, and recording over longer periods of time is significantly more laborious than using questionnaires.

3.1.4.3 Health

Different aspects of health were captured by self-administered questionnaires (i.e. diseases, disability, health care services utilization, health-related behavior), computer assisted personal interview (i.e. history of selected physician-diagnosed conditions), physical measurement and tests (i.e. anthropometry, blood pressure, heart rate), and laboratory tests (i.e. general health indices as clinical chemistry,red blood count, or urine status). Originally, the health topic was based in the core survey. While some indicators which can be seen as indicators of a persons health status, like e.g. anthropometrics or BMI, had been also a part of MoMo since the baseline survey, several more indicators were added due to the missing KiGGS wave in the run-up of Wave 3. Due to the reduced resources for wave 3, not only the scope of the survey on the health status of the participants had to be shortened, but also no medical data such as blood or urine samples are available.

3.1.4.4 Other factors

In addition to the information on participant motor performance, respectively physical fitness, physical activity, and health, sociodemographic parameters were recorded during the study. Those parameters included gender, age, social status, migration background, residential region (western Germany vs eastern Germany), and residential environment (urban vs rural). Social status was assessed in the three categories parental educational status, parental profession, and net household income. Separate status were calculated for each of the three components and then the sum was calculated over the three categories. From T1 to T3 the sociodemographic parameters were assessed by KiGGS. For T4 those parameters were included in MoMo.

3.2 Study sample

The cross-sectional sample and the longitudinal sample used for the analyses are described in the following section. The samples on which the analyses in Articles 2 and 3 are based are described in the respective article.

3.2.1 Pooled sample

The pooled sample shown in Table 3.2 includes each participant in the study at their first visit. Thus, each participant is included exactly once, regardless of whether they participated more than once or not. This sample can be used to assess whether there is a general relationship between the variables of interest. For example, it can be assessed whether participants who report more physical activity also report better health. This sample is also used to describe the physical activity and the physical health in children and adolescents in Germany.

Table 3.2: Pooled sample description: sex and age-group at study entry

	4/5 y.	6-10 y.	11-13 y.	14-17 y.	total
female	1045 (49.0 %)	2584 (48.4 %)	1150 (48.4 %)	1523 (51.0 %)	6302 (49.1 %)
male	1088 (51.0 %)	2753 (51.6 %)	1226 (51.6 %)	1463 (49.0 %)	6530 (50.9 %)
total	2133	5337	2376	2986	12,832

3.2.2 Longitudinal sample

A total of 1,407 subjects participated in MoMo baseline, Wave 1 and Wave 2, completing three survey in about 15 years. The mean age difference between the first and the third individual survey was 11.5 years. Minimal difference was 10.8 years and maximal difference was 14.5 years. In half of the sample the difference was between 11.0 years and 11.6 years. The variation in the difference is mainly caused by organizational issues which made it necessary to adapted the order in which the points (municipalities) were visited between the surveys. Possible reasons were the availability of trained personal or adequate locations. Moreover, participants who moved between the survey waves within Germany were invited to the nearest point from their new place of residence.

This sample was used to assess change over time. For example, a person who was active at the first survey might report better health at a later wave.

Table 3.3: Longitudinal sample description: sex and age-group at baseline

	4/5 y.	6-10 y.	11-13 y.	14-17 y.	total
female	259 (56.3 %)	302 (54.1 %)	114 (55.1 %)	106 (58.2 %)	781 (55.5 %)
male	201 (43.7 %)	256 (45.9 %)	93 (44.9 %)	76 (41.8 %)	626 (44.5 %)
total	460	558	207	182	1,407

After the description of the two samples used to analyze the relationship between physical activity and physical health, the following section looks at the data set of the MoMo study.

3.3 Overview of the MoMo dataset

Figure 3.2 visualize the structure of the MoMo data set. The MoMo dataset consists of the master data and the actual survey data.

The master data includes the participant number (ID), age and gender of the person. In addition, information can be found here on which parts of the study the person participated in, including the respective survey dates.

The MoMo data set can be categorized in different ways. The content can be divided into the areas of physical fitness, physical activity, and health. These core areas are supplemented by information on factors that are assumed to influence the target values. Based on the data collection method, a distinction can be made between measured and surveyed data.

Most of the data in the activity section comes from the MoMo Physical Activity Questionnaire (MoMo-PAQ). Since wave 2 (2014-17), this has been supplemented by a device-based recording of activity using an accelerometer.

The physical fitness is measured in the field via the MoMo test battery. The test tasks relevant to this thesis are described in section 3.4.2. Further information on the test battery can be found in *Testmanual zu den motorischen Tests und den anthropometrischen Messungen* (Worth et al., 2015).

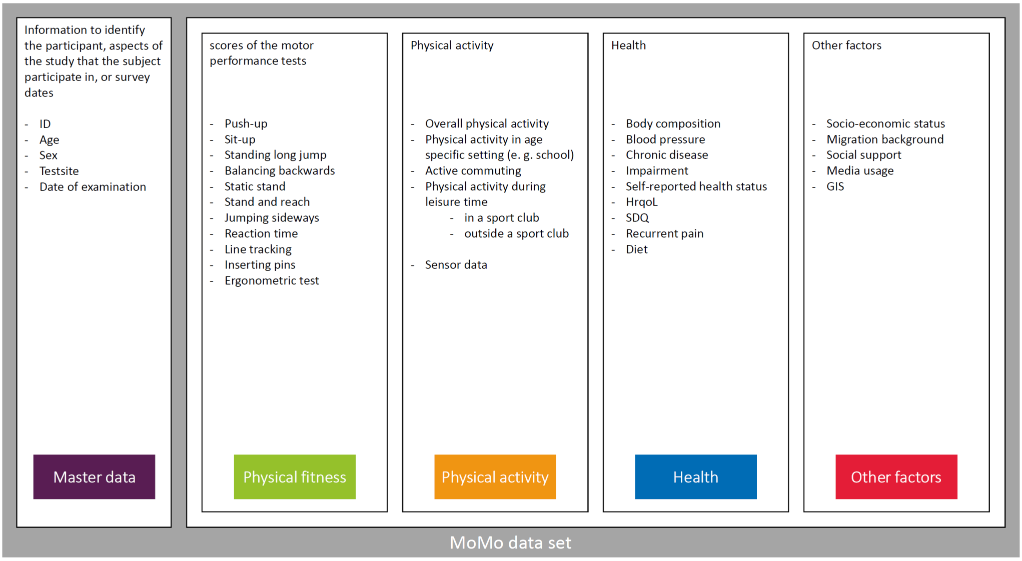


Figure 3.2: Structure of the MoMo data set (own representation)

The health data includes information from the questionnaire, as well as measured values for body composition or blood pressure.

3.4 Methodology in analyzing physical activity and health correlation

As both physical activity in daily life and sport are of interest in the context of health behavior, various aspects of physical activity are recorded in the MoMo study. Therefore, the understanding of physical activity on which MoMo is based includes everyday activity and organized activity in leisure or at school (Bös, 2009). Physical activity includes any physical movement that is performed by the skeletal muscles and leads to increased energy consumption (Caspersen et al., 1985).

In order to examine the relationship between physical activity and health, health and health-related aspects must also be recorded. The link to KiGGS made it possible to associate many health aspects of the subjects with their physical activity behavior. Some aspects, especially those that are thought to be stable only in the short term or to be closely related to physical activity behavior, were also recorded in the MoMo Survey.

3.4.1 Recording physical activity in MoMo

The extent of physical activity is described by type of activity, frequency, duration, and intensity. According to the concept of HEPA (Health Enhancing Physical Activity), the study includes both everyday activities such as active transport to school, and physical activities in different settings such as school or sports clubs and others.

Physical activity assessment within MoMo focuses on the following core areas (cf. table 3.4). Since the baseline study (2003-2006), the physical activity is captured by the MoMo Physical Activity Questionnaire (MoMo-PAQ) (Bös, 2009; Jekauc et al., 2013). With the help of the core areas shown in Table 3.4, the MoMo-PAQ attempts to gain a comprehensive insight into the activity behavior of the participants.

Table 3.4: Areas of PA in the MoMo-PAQ

Area of PA	description
Overall Physical Activity	Number of days per week on which at least 60 minutes of physical activity of at least moderate intensity was achieved.
PA in age-specific setting	The physical activity that is practiced in the relevant setting (kindergarten, school or workplace). Examples include supervised physical activity time in kindergarten, sports lessons at school or physically demanding activities at work.
Sport activity	Sporting activity within and outside sports clubs.
Everyday PA	Physical activity in everyday life. It includes free play, transportation on foot or with non-motorized aids, such as bicycles, as well as housework or gardening.

Since MoMo Wave 2 (T3: 2014 - 2017), physical activity has also been recorded using acceleration sensors. ActiGraph GT3X+ and wGT3X-bt accelerometers (Actigraph, LLC, Pensacola, FL, USA) were used in MoMo (Burchartz, Manz, et al., 2020; Burchartz et al., 2021, 2022). The participants were asked to wear the sensor for one week after visiting the study center where they completed the MoMo-PAQ and the motor performance tests. The sensor was attached by an elastic belt and had to be worn on the right hip for all waking hours. After one week the participant sent the sensor back to the study team where the data was downloaded and analyzed. A minimum wear time of 8 hours on four weekdays and one weekend day was considered as the threshold for a valid data set.

Meanwhile, a 24h protocol is recommended to monitor not only PA, but physical behavior (PB) including its components PA, sedentary behavior, and sleep Burchartz, Anedda, et al., 2020; Rosenberger et al., 2019. Capturing the whole day, the use of a 24h protocol reduces missing information caused by non-wear periods. Moreover, the approach creates the opportunity to analyze the inter-relatedness of health effects of PA, SED, and sleep Rosenberger et al., 2019. Therefore, in the preparation phase of the successor survey MoMo 2.0 it was decided to change the type of accelerometer used to measure the PA. As sensor the activPAL (PAL Technologies Ltd., Glasgow, UK) was chosen. The activPAL is a lightweight unit that is attached by medical tape to the thigh of the subject.

While device-based assessment of PB is state of the art, the data from the MoMo-PAQ is an essential part of MoMo. As already mentioned, the devices were not included in the study until later and therefore device-based acceleration data is only available from MoMo Wave 2 (T3: 2014-2017) onwards. In addition, wearing the sensors, like all other parts of the study, is based on the willingness of the participants. Last but not least, while the devices-based data gives a good overview of the participants' PA in terms of total duration, frequency, or intensity, the sensors fail to provide information about the type of activity or the context in which the subject engaged in it. But, this kind of information is no less important when you try to understand the effects of PA on health.

The following section describes the core areas of PA captured with the MoMo-PAQ. Each description is illustrated by a descriptive insight into the data from the MoMo study. Those insights are based on a pooled data set overall survey waves. For participants of the longitudinal arm of the study, only the data of their first measure is considered here to avoid distortions caused by different re-participation rates. The analyses of the longitudinal data are the rationale of section 4.4.

Overall physical activity

The initial two components of the MoMo-PAQ prioritize overall physical activity, irrespective of contextual factors. The two items assess the number of days in the previous seven days, or in a typical week, that the subject engaged in at least 60 minutes of moderate to vigorous physical activity. These metrics form the basis for assessing whether an individual meets international recommendations, such as those stipulated by the WHO in 2010, which stipulate at least 60 minutes of MVPA per day for children and adolescents (World Health Organization, 2010).

Everyday physical activity

The everyday physical activity includes all activities that are part of daily life, whereby sports activities are not included. The MoMo-PAQ inquires about gardening/working in agriculture, housework, walking, cycling, and the utilization of other non-motorized means of transportation (e.g., skateboard), and playing outdoors. The frequency (number of days per week), duration (in minutes per day), and intensity of gardening, working in agriculture, and playing outdoors are measured. For walking and other means of transportation, the daily distance and regular intensity are documented. The total minutes per week are calculated by multiplying the frequency and duration of each activity and summing them up. The average daily distance traversed while walking and cycling is then converted into a number of minutes and multiplied by seven, subsequently being summed.

Sports activity

The MoMo study focuses on two areas of sporting activity. In addition to sporting activity that is pursued within the framework of a sports club, MoMo also documents sporting activity that occurs outside of such organizational forms, such as running alone or in a group.

In both cases, up to four sports can be named, for which more detailed information is then recorded. The participants are asked to report their engagement in competitive sports, the weekly frequency of their training, and the months during which they engage in sports. Furthermore, the intensity with which each sport is usually practiced is recorded. An annual factor is derived from the specified months, which is then multiplied by the minutes of the respective sport. This approach ensures that sports engaged in infrequently are not overestimated (Schmidt et al., 2016). The summation of all sporting activities yields the total weekly minutes devoted to sports. This calculation can be performed for the total sporting activity or for sporting activity within and outside of sports clubs, respectively, if such a distinction is deemed necessary.

Physical activity in age-specific settings

Regarding the target population of the study, there are three relevant age-specific settings. Firstly, the majority of the target group goes to school, as children in Germany are generally required to attend school from the age of 6. To assess the physical activity in the setting school curricular as well as extracurricular activities are captured. For the assessment of physical education, frequency, total minutes per week, and intensity of the activity are captured. Moreover, the participants are asked to indicate if they engage in any extracurricular activities, and if they do so, the frequency, duration, and intensity of those activities are captured as well. Total minutes of physical or sporting activity within the school are calculated by summing up the total minutes of physical education per week and the minutes in extracurricular sports. This sum is then multiplied by a factor to account for holidays (Schmidt et al., 2016).

Secondly, children in Germany usually attend kindergarten before they start school. The supervised physical activity time per week is recorded for this group. The frequency per week, the total duration of the supervised physical activity time over a week, and the intensity of the activity are recorded. To calculate the total minutes of an average week, the supervised PA time per week is multiplied by a factor to account for holidays as in the school setting.

Third, the last relevant setting is the workplace, as school can be left after the ninth grade and vocational training can be started. To assess PA at the workplace the participant is asked in which month he or she works, and on how many days in a normal week the work contains physically demanding tasks for more than ten consecutive minutes. In addition, the participant is asked how much time he or she spends in different intensities during those physically demanding tasks. For the total minutes of physical activity at the workplace, the minutes in the different intensity categories are summed up and multiplied by the number of days on which physically demanding activities are performed for more than 10 minutes at a time.

Device-based physical activity

As already mentioned, the device-based assessment via accelerometer was implemented in Wave 2 (T3: 2014-2017). The sensors were attached to an elastic belt and worn on the right hip. The signal from the sensor can be used to derive the steps taken by the test person and the time spent in different intensity classes. The data can be viewed continuously or aggregated over a reference period. In MoMo, the aggregated data is primarily used in conjunction with other factors such as health or motor performance. The average time of physical activity with at least moderate intensity is particularly important here.

Another advantage of the sensors is that, in addition to physical activity, they can also detect periods of physically inactive behavior, such as sedentary activities. However, it should be noted that wearing the sensors on a hip belt can underestimate activities in which the hips remain relatively still, such as cycling. Sensors worn on the thigh, as used in the follow-up project MoMo 2.0, provide a better recording here.

3.4.2 Recording health in MoMo

Overweight and obesity

One of the most commonly used indicators for assessing body composition is the BMI. It was also calculated in MoMo. Height and weight were measured by trained test supervisors during the field studies, and the BMI was then calculated and classified using reference values.

In addition to height and weight, hip and waist circumferences were also measured. This data is used to calculate further indicators such as the waist-hip ratio or the waist-height ratio.

In addition, body composition was measured using bioelectrical impedance analysis (BIA). The measurement provides information on the absolute and relative body fat mass as well as other parameters such as the phase angle, which can be used to assess the training and nutritional status of the body.

Recurrent pain

In the questionnaire, the participants were asked, among other things, about the recurring occurrence of various pains. They were asked about the occurrence in the last three months before the examination. The subjects could indicate whether the pain had not occurred, occurred once or occurred repeatedly. Various regions were queried, such as the head, abdomen or back. The female participants were also asked about the occurrence of menstrual cramps.

Self-rated health

Participants were asked to assess their general state of health. The *Minimum European Health Module (MEHM)* was used to assess general health. The module includes three aspects. Firstly, an assessment of general health on a five-point scale ranging from very good, good, fair, poor and very poor. Secondly, the recording of chronic illnesses and, thirdly, the question of whether the participants are restricted in their daily lives for health reasons.

Cardiorespiratory fitness

In the model of Bouchard physical fitness is a mediator between physical activity and health. Another point of view is that physical fitness can be seen as a measurement of the functionality of the body and therefore it can be considered as a maker of health (Ortega et al., 2008).

The three main components of physical fitness that are relevant in a health-related context are cardiorespiratory fitness (CRF), muscular fitness, and speed (Ortega et al., 2008). This thesis focuses primarily on the CRF.

In MoMo CRF was assessed during field testing using the Physical Working Capacity 170 (PWC170) cycle ergometry test. The test was performed on a stationary bicycle (Ergosana, Germany). The initial workload was calculated on the basis of body mass (baseline(T1)), or age (since wave1 (T2)) and increased incrementally every 2 minutes. Further information on the protocols used can be found elsewhere (baseline: Bös, 2009; since wave1: Worth et al., 2015). Participants followed the progressive protocol until their heart rate exceeded 190 bpm for at least 15 seconds, their cadence dropped below 50 rpm for at least 20 seconds, or they decided to stop due to exhaustion. Power output (in watts) at a heart rate of 170 bpm (PWC170) was determined by interpolation or extrapolation of the measured data in Excel.

The previous chapter introduced the procedure and data set of the MoMo study, which is the basis of the dissertation. The following chapter focuses on the results of the analysis of the data to answer the research questions of the dissertation (see section 1.3) . Therefore, it presents data on physical activity, physical health, and the relationship between these two constructs derived from the MoMo data.

4 Results

The following chapter presents findings on physical activity and physical health among children and adolescents in Germany and the relationship between the two constructs. The chapter includes Paper II and Paper III of the dissertation, as well as selected other findings from the MoMo study.

4.1 Results of selected aspects of physical activity reported in the MoMo study

Physical activity measures are here presented as a summary score of an age group or birth cohort. This gives you the distribution for each group, e.g. for all eight-year-olds. The groups can be compared with each other and statements can be made as to whether one group is more or less active than another. It is important not only to look at a positional measure such as the mean value, but preferably at the distribution as a whole in order to reduce the influence of outliers.

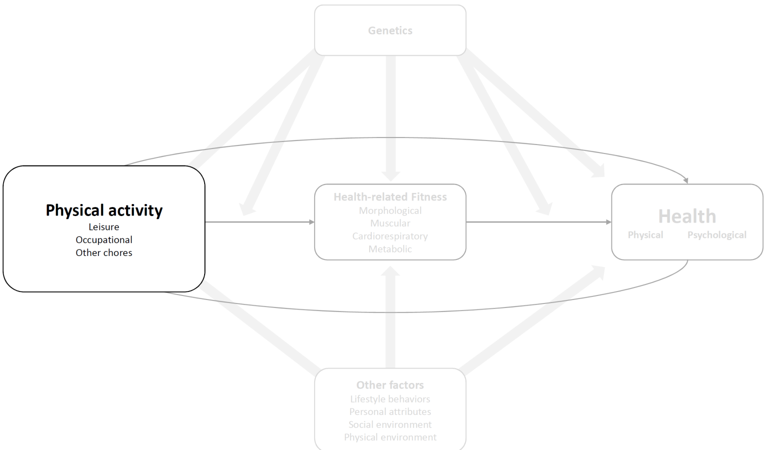


Figure 4.1: Physical activity in the model of Bouchard (cf. Bouchard et al., 2012)

A pooled sample of all participants at their first appearance in MoMo was used for the descriptive analysis. A detailed description of the sample can be found in section 3.2.1. The figure 4.1 shows which section of the Bouchard model the following section refers to.

4.1.1 Overall physical activity

To capture overall physical activity the subjects were asked for the number of days with at least 60 min of MVPA during the last week and a normal week. The answers ranged from zero to seven for both items. The mean was calculated from both items. To enable a clearer presentation, the mean values are reduced to whole days in the following.

Overall, most of the subjects reported 3 or 3.5 days on average (19.3 %), followed by 4 or 4.5 days (16.0 %) and seven days (15.3 %). The least frequent answers were 0 or 0.5 days (2.2 %) followed by 1 day or 1.5 days (7.5 %).

Looking at the answers by age group, the distribution in the two younger groups differ clearly from that in the older ones. In the participants under six years of age, nearly 30 % reported seven days with at least 60 min of MVPA per week. Seven days per week was also the most frequent answer of the 6-10-year-old (19.1 %). In comparison, the share of subjects that reported 7 days with at least 60 min of MVPA drops remarkably for the older ones to 7.8 % in the 11-13-year-old and 4.6 % in the oldest group (14-17 y.). Table 4.1 shows the frequencies grouped by sex and age group.

Table 4.1: Number of days with at least 60 min of MVPA by age group and sex

days	**4-5 y.**		**6-10 y.**		**11-13 y.**		**14-17 y.**		**all**
	m	f	m	f	m	f	m	f	
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
0	9 (0.9)	13 (1.3)	24 (0.9)	27 (1.1)	21 (1.8)	41 (3.7)	46 (3.3)	86 (5.9)	267 (2.2)
1	62 (6.1)	49 (5.0)	110 (4.2)	144 (5.8)	89 (7.6)	131 (11.8)	119 (8.5)	200 (13.7)	904 (7.4)
2	104 (10.2)	129 (13.0)	293 (11.2)	315 (12.8)	172 (14.7)	207 (18.7)	245 (17.4)	344 (23.6)	1809 (14.8)
3	120 (11.7)	129 (13.0)	442 (17.0)	465 (18.8)	270 (23.1)	264 (23.8)	340 (24.2)	343 (23.5)	2373 (19.4)
4	128 (12.5)	123 (12.4)	411 (15.8)	432 (17.5)	217 (18.6)	193 (17.4)	257 (18.2)	192 (13.2)	1953 (16.0)
5	140 (13.7)	154 (15.6)	429 (16.5)	349 (14.1)	176 (15.1)	132 (11.9)	204 (14.5)	146 (10.0)	1730 (14.2)
6	133 (13.0)	120 (12.1)	361 (13.9)	301 (12.2)	123 (10.5)	64 (5.8)	119 (8.5)	93 (6.4)	1314 (10.8)
7	**326 (31.9)**	**272 (27.5)**	**534 (20.5)**	**435 (17.6)**	**100 (8.6)**	**76 (6.9)**	**78 (5.5)**	**55 (3.8)**	**1876 (15.3)**

Note: **bold numbers** indicate adherence to WHO recommendation for physical activity from 2010 (at least 60 min MVPA per day).

The 2010 version of the WHO's physical activity recommendation suggests at least 60 minutes of MVPA per day for children and adolescents. Applied to the question, this means that the proportion of those who state that they achieve this 60 min on all seven days in the last week and in a normal week are those who fulfill this recommendation (last row of table 4.1). Based on our self-reported data the recommendation is most often fulfilled by boys under the age of six (32.0 %) followed by the girls of the same age (26.8 %). Overall, the adherence to the WHO recommendation from 2010 is 15.3 % in the pooled sample. As mentioned, the adherence decreases over the age groups, and the adherence is higher in boys than in girls for all groups.

4.1.2 Sport activity organized within a sport club

Over 60 % of the participants reported to be member of at least one sport club. The frequency in the male subjects (65.3 %) was slightly higher than in the female (57.4 %). Most sports club members were found in age groups 2 (6-10 y.) and 3 (11-13 y.) for both boys and girls. Unlike the proportion of sports club members, which is highest in the two middle age groups and decreases again in the older age groups, the average duration of physical activity in a sports club increases with age. While the youngest reported an average of 86 ± 51 min and 78 ± 44 min per week respectively, the 14-17-year-olds reported an average duration of 201 ± 148 min and 255 ± 168 min in the same period. Figure 4.2 shows the minutes of PA over the age groups.

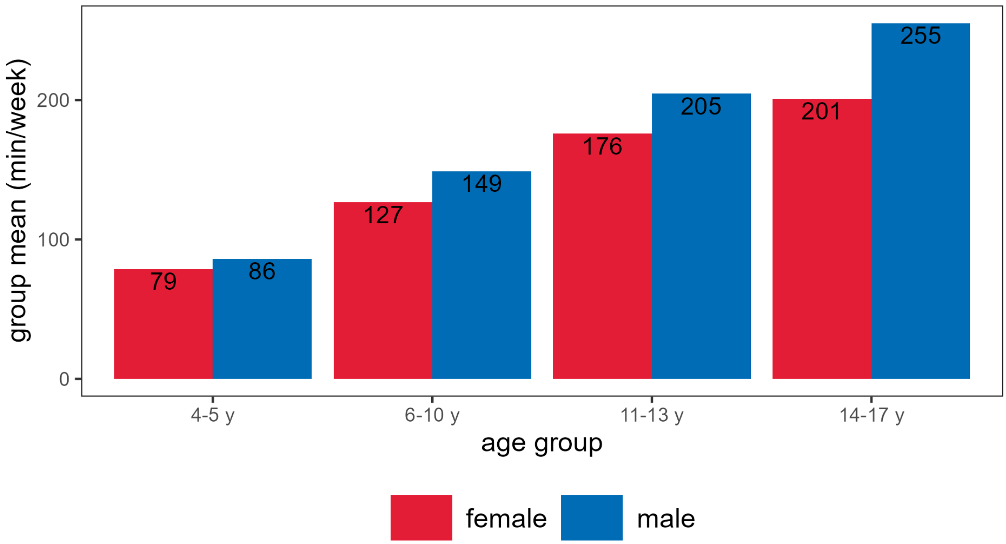


Figure 4.2: Leisure time sport activity within a sport club (mean minutes peer week) by age and sex

4.1.3 Sport activity during leisure time

Nearly half of the participants (45.8 %) reported that they participated in some form of self-organized sports activity such as working out or running during their leisure time. The shares were nearly even in female and male subjects, and rise for both sexes over the age groups. For both sexes, there is a significant increase in the average minutes reported between the second and third age groups. However, the two younger age groups and the two older groups did not differ from each other. The reported mean minutes of leisure time sport activity ranged from 98 ± 106 min for females and 120 ± 135 min for males in four and five year olds to 135 ± 134 min for females and 175 ± 169 min for males in the oldest group (14-17 y.). Mean minutes of leisure time sport activity per group are shown in figure 4.3.

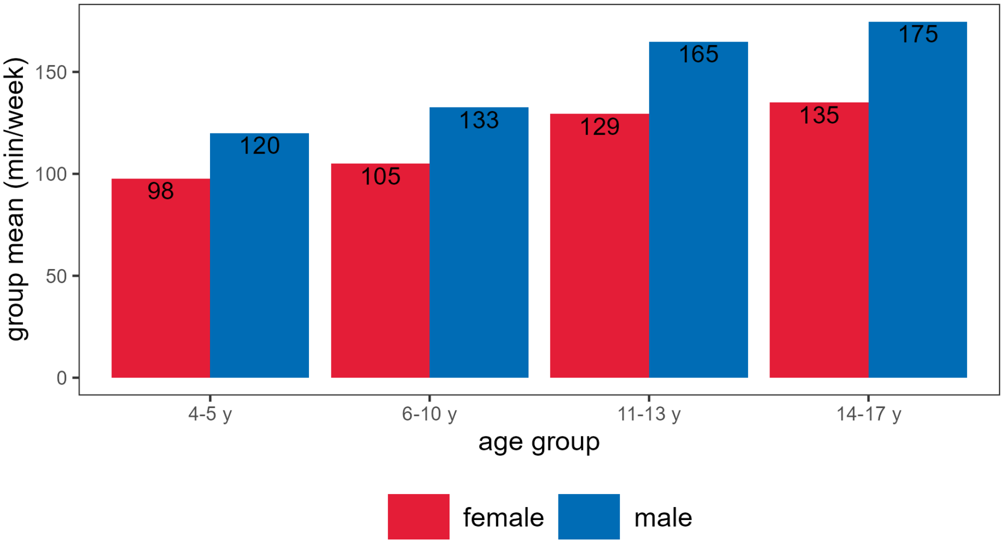


Figure 4.3: Leisure time sport activity outside of a sport club (mean minutes peer week) by age and sex

4.2 Results of selected aspects of health aspects reported in the MoMo study

In order to understand a problem, one must first be clear about the nature of the problem and the factors that influence it. Having discussed different definitions of health and the collection of different indicators to assess health status in the previous chapters, we now look at the factors that influence the health of the individual and the health indicators included in MoMo to describe the health status of a participant.

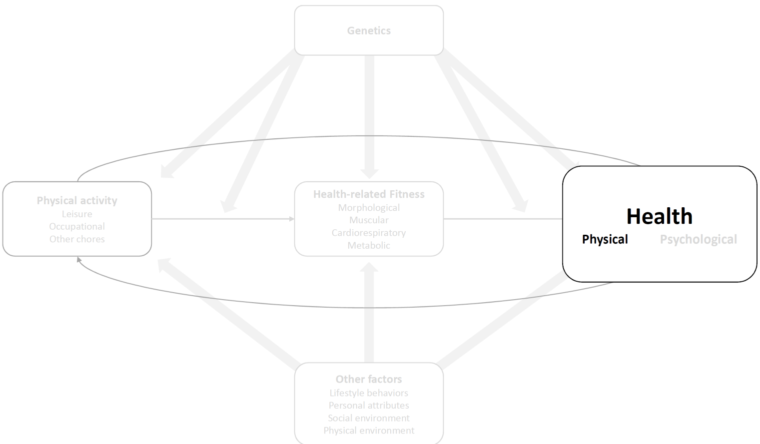


Figure 4.4: Localization of the topic of the section in the model of Bouchard

While health is complex and multi factorial, the paths leading to the manifestation of a disease are also complex, heterogeneous, and characterized by considerable individual differences (Bouchard et al., 2012). The evidence suggests that genetic differences, the physical and social environment, and behavioral patterns contribute in varying degrees to the health of an individual. Obesity, type 2 diabetes, or various heart disease are examples for chronic conditions known to aggregate in families, suggesting the involvement of genetic factors (Bouchard et al., 2012). However, chronic diseases are largely preventable because strong evidence points out that behavioral factors such as poor nutritional habits, smoking, low levels of physical activity, among others, are associated with an increased risk of death or morbidity (Bouchard et al., 2012).

4.2.1 Overweight

BMI and its classification of weight status are often used as an indicator of physical health, as described in the first article (see section 2.2) of this dissertation. The classification of BMI values as overweight or obese enables a rapid evaluation of someone's weight status. As childhood and adolescents are a time of growth and therefore serious bodily changes among other, a valid reference is needed for the classification. For Germany, the reference data stratified by age and sex were derived from the data of the KiGGS survey by Kromeyer-Hauschild et al. (Kromeyer-Hauschild et al., 2001). Based on this reference a subject is classified as severely underweight below the third percentile of its strata, as underweight from 3rd to 10th percentile, normal weight from 10th to 90th percentile, overweight above the 90th percentile, and obese above the 97.5th percentile.

In the pooled MoMo sample (cf. tab 3.2), 2.2 % of children and adolescents are severely underweight, 7.7 % are underweight (including severely underweight), 12.2 % are overweight (including obese) and 4.8 % are obese. The share of overweight or obese subjects did not differ between male (12.10 [11.27, 12.98] %) and female (12.38 [11.52, 13.28] %) subjects, but between the age groups. The shares of overweight or obese subjects are shown in table 4.2.

Table 4.2: Share of overweight or obese subjects by age and sex

sex	age	n	%overweight or obese
female	4-5 y.	971	7.7 [6.2, 9.6]
	6-10 y.	2194	12.5 [11.2, 14.0]
	11-13 y.	993	14.4 [12.4, 16.7]
	14-17 y.	1215	14.2 [12.3, 16.2]
male	4-5 y.	998	7.8 [6.3, 9.7]
	6-10 y.	2339	11.7 [10.4, 13.0]
	11-13 y.	1080	14.4 [12.4, 16.6]
	14-17 y.	1228	14.4 [12.6, 16.5]

4.2.2 Self-rated health

Considering the fact that the question is answered by a parent, the participant together with a parent, or by the subject itself, the item is not comparable across the entire sample. It is assumed that for the first age group (4-5 y.) the question is answered by the parents, for the second group

(6-10 y.) the question is read and explained to the subject and answered together, and for the older groups the question is answered by the subject. Therefore, the age groups should be analyzed separately.

Table 4.3: Self-rated health status by age and sex

sex	age	n	%fair or worse[1]
female	4-5 y.	1006	4.3 [3.2, 5.7]
	6-10 y.	2492	3.5 [2.8, 4.3]
	11-13 y.	1113	5.7 [4.5, 7.2]
	14-17 y.	1474	10.9 [9.4, 12.6]
male	4-5 y.	1046	5.3 [4.1, 6.8]
	6-10 y.	2662	4.8 [4.0, 5.7]
	11-13 y.	1187	6.5 [5.2, 8.0]
	14-17 y.	1424	9.0 [7.6, 10.6]

[1] share of subjects that rated their health as fair, bad or very bad

4.2.3 Cardiorespiratory fitness

The PWC170 is used in MoMo to determine CRF. The peak performance of the PWC170 showed a strong correlation with the subjects body weight $r(7376) = .78$, $p > .001$. Therefore, the performance achieved is divided by the body weight to control for it. The mean performances and the relative PWC170 are presented in table 4.4. Absolute performance at 170 bpm increases with age for both sexes, with higher means in male subjects for each age group. The means of relative performance are also higher in the male subjects than in their female counterparts, but while the oldest group achieved the highest values among the males, the 11-13 year olds were the highest among the females.

4.2.4 Recurrent pain

Analyses from MoMo and KiGGS show that head, abdominal, and back pain are the most common types of pain experienced by children and adolescents in Germany (Kolb et al., 2022; Krause et al., 2019). Headaches were the most frequently mentioned pain among both female and male participants. In the cross-sectional sample, one of four participants reported recurrent headaches,

Table 4.4: Means and standard deviation for PWC and PWCrel stratified by age and sex.

sex	age	PWC (Watt)	PWC rel (Watt/kg)
female	4-5 y.		
	6-10 y.	55.8 (16.7)	1.85 (0.45)
	11-13 y.	87.4 (22.3)	1.87 (0.45)
	14-17 y.	107.2 (29.1)	1.82 (0.46)
male	4-5 y.		
	6-10 y.	65.8 (19.9)	2.17 (0.51)
	11-13 y.	103.5 (27.3)	2.20 (0.52)
	14-17 y.	149.5 (39.1)	2.30 (0.54)

with higher frequencies in girls (28.6 %) than in boys (22.0 %). The frequency of reported recurrent headaches also increases from age group to age group.

4.3 Relationship between physical activity and health

The cross-sectional view of the relationship between physical activity and physical health is the main objective of Paper II *Physical activity and recurrent pain in children and adolescents in Germany – results from the MoMo Study*. The paper analyzes whether the prevalence of recurrent headache differs between different activity levels. The WHO recommendation of 60 minutes of MVPA per day is used as a threshold. A second focus of the paper is to analyze whether those who report recurrent headaches spend less time active. Average time spent in MVPA measured by accelerometry is used.

Physical activity and recurrent pain in children and adolescents in Germany – results from the MoMo Study

Slightly modified version of Paper II published on 28th October 2022.

Abstract: Recurrent pain can be a significant disruption in the activities of daily life, and is not only a health problem in adults, but also in children and adolescents. This study analyzed the prevalence of recurrent pain in the current sample (n = 1516; 11–17 years (mean$_{age}$ = 14.4 $\pm$ 2.0 years); 50.8% female) of a nationwide study in Germany, evaluated the association of participants’

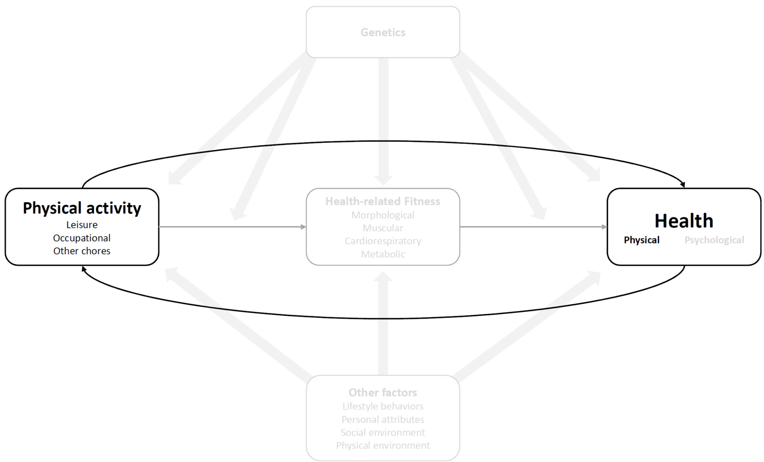


Figure 4.5: The relationship between physical activity and health (cf. Bouchard et al., 2012)

device-based physical activity (PA) with the prevalence of recurrent pain, and assessed whether children and adolescents who reported pain for the last three months accumulated less PA than those who did not. A higher prevalence was found in girls for recurrent headaches (42.2% vs. 28.7%), abdominal pain (28.2% vs. 20.1%), and back pain (26.9% vs. 19.5%). We found higher odds for recurrent headaches in girls (OR = 1.54) and in participants that did not reach at least 60 min of moderate to vigorous PA (MVPA) per day (OR = 2.06). Girls who reported recurrent headaches accumulated 4.7 min less MVPA per day than those without. The prevalence of pain remains at a high level in the German youth and underscores the need for interventions to improve the health situations of children and adolescents.

Keywords: headache; abdominal pain; back pain; motor performance; physical fitness; KiGGS

Introduction

Recurrent pain is not only a health problem in adults, but also in children and adolescents (Nieswand et al., 2019, 2020; Perquin et al., 2000; Roth-Isigkeit et al., 2003), and can cause significant disruptions in daily activities (Nieswand et al., 2019, 2020; Palermo, 2000). Affected children have more absences from school and participate less frequently in athletic or social activities (Nieswand et al., 2020; Palermo, 2000). Furthermore, the utilization of medical care and medications increases in this group (Du et al., 2012; Ellert et al., 2007; Krause and Mauz, 2018). Additionally, recurrent pain has been shown to affect well-being. This can manifest itself, for example, in a reduced quality of life (HRQoL) or emotional problems such as anxiety and depressiveness (Krause and Mauz, 2018; Krause et al., 2017).

Although the scientific evidence is limited, PA and especially aerobic activities are regularly recommended to migraine patients (Busch and Gaul, 2008; Hammond and Colman, 2020). The results of a study by Pilati et al. showed a protective effect in women and support the protective role of exercise with regard to migraines (Pilati et al., 2020). Others found moderate evidence that aerobic exercise reduces the number of migraine days, but only low evidence for decreased duration of the attacks and intensity of pain (Lemmens et al., 2019). In a qualitative interview study, low-intensity PA was mentioned by adolescents to be helpful in coping with headaches (Skogvold and Magnussen, 2019). However, in another study, PA did not show a predictive function for any of the studied headache disorders (Kröner-Herwig and Gassmann, 2012). A meta-analytic review of the hypoalgesic effects of exercise revealed highly variable magnitudes and directions of the effects in the chronic pain group, depending on the pain condition and the intensity of the exercise (Naugle et al., 2012). A possible mechanism to explain exercise-induced hypoalgesia is the release of peripheral and central beta-endorphins during exercise, which influence pain sensitivity (Naugle et al., 2012). In addition to the neurovascular processes, other cardiopulmonary as well as inflammatory processes come into question to explain how improved aerobic fitness affects pain and the perception of it (Irby et al., 2016).

Part of the conflicting results may be due to the fact that a single dose of physical activity can trigger pain or can cause a pain condition to worsen, while regular physical activity can help relieve pain by increasing serotonin levels and increasing opioids in the central inhibitory pathway (Lima et al., 2017).

Another point that must be considered in connection with the different results is the recording of PA. Most of the studies assessed PA via self-reports. Some studies ask about the number of days of physical activity without considering duration, type, and intensity (Robberstad et al., 2010). Other studies, especially in the field of therapy, are based on a specific exercise program, the effectiveness of which is tested. In principle, different types and intensities of physical and sporting activity have different effects on the body, and therefore different effects on pain conditions or the perception of pain are to be expected.

Moreover, PA has also been found to be beneficial in the treatment of several conditions commonly associated with migraines (e.g., obesity, hypertension, and depression) (Irby et al., 2016). Obesity and low levels of PA also demonstrated an independent as well as a combined association with recurrent headaches in adolescents (Robberstad et al., 2010).

Numerous studies from different European countries and other parts of the world have shown an increasing prevalence of headaches, among others, in recent years (Albers et al., 2015; Holstein et al., 2018; Jacobsena et al., 2011; Nieswand et al., 2020; Philipp et al., 2019; Torres-Ferrus et al., 2019; Wilkes et al., 2021). For Germany, the prevalence of recurrent pain is assessed by the nationally representative German Health Interview and Examination Survey for Children and Adolescents (KiGGS) within the framework of health monitoring at the Robert Koch Institute (RKI) (Hölling et al., 2012).

In the KiGGS baseline study (2003–2006), more than half of children and adolescents aged 11 to 17 years reported recurrent pain (Ellert et al., 2007). Headaches, abdominal pain, and back pain were the most frequently mentioned pain locations (Ellert et al., 2007). The prevalence was higher in girls compared with boys and in the older group (14–17 years) compared with the younger group (11–13 years) (Ellert et al., 2007). While only minor changes in prevalence were observed in KiGGS Wave 1 (2009–2012) (Krause et al., 2017), the following KiGGS Wave 2 (2014–2017) revealed significant increases in the prevalence of recurrent headaches, among other pains (Krause et al., 2019). The relation with sociodemographic variables was investigated, but neither stratification by socioeconomic status (SES) nor migrant background revealed consistent differences (Krause et al., 2017).

Due to the fact that sustainable measures can only be planned and well-founded decisions made on the basis of current data and regular surveillance, one objective of the present study was to update the prevalence of recurrent pain in children and adolescents in Germany based on a current sample of the Motorik-Modul Study (MoMo) Wave 3 (2018–2020) and to compare it with the prevalence reported in previous surveys (i.e., KiGGSWave 2). Furthermore, the present study assessed the association between PA and recurrent headaches, which, as shown by the previous studies, are the most common type of pain in children and adolescents in Germany. Therefore, PA is captured via accelerometry and evaluated based on the recommendation of the World Health Organization (WHO). Regarding the potential mechanisms linking enhanced cardiovascular fitness and migraines, we would expect an active lifestyle to lower the odds of recurrent headaches. Additionally, the study examined whether self-reported pain in the past three months reduces devicebased measured MVPA levels.

Material and methods

Procedure and participants

The KiGGS core survey is supplemented by different in-depth modules [28]. One of these in-depth modules is the Motorik-Modul Study (MoMo) (Woll et al., 2017a). The main objectives of MoMo are to analyze the developmental and temporal trends in motor performance (MP), physical fitness (PF), and physical activity (PA), as well as their underlying influencing factors (Bös, 2009; Woll et al., 2017a). In addition, MoMo assesses the impact of MP/PF and PA on the health development of children and adolescents (Bös, 2009; Woll et al., 2017a). The selection for the representative cohort of MoMo Wave 3 was conducted according to the established procedure of the former waves. At the first level, the municipalities of the former waves were retained. In the second step, a stratified sample was randomly selected from the addresses submitted. More information about the sampling procedure can be found elsewhere (Kurth et al., 2008). The selected persons were invited to participate in the study by letter. Participation in the study was voluntary, and written consent was obtained prior to data collection. Under the age of 15, the participants had to be accompanied by a legal guardian. Each participant received an incentive after participating.

The MoMoWave 3 data collection started in August 2018 and was scheduled to end in June 2020. Due to the COVID-19 lockdown in Germany, MoMo Wave 3 had to be interrupted in March 2020. Therefore, only data collected between August 2018 and March 2020 were used. All tests were carried out by trained personnel.

In total 2,843 participants (48.3% female) were enrolled in MoMo Wave 3. The preliminary response was 25.2% [31]. This results in a sample of 1516 participants, consisting of 770 girls (age = 14.5 $\pm$ 2.0 y., MVPA = 34.8 $\pm$ 18.3 min/day) and 746 boys (age = 14.3 $\pm$ 2.0 y., MVPA = 39.7 $\pm$ 20.1 min/day).

The STROBE statement guided the reporting of this study (Vandenbroucke et al., 2007).

Measures and variables

Except for the device-based measured PA, the data in the current study were self-reported by the participants and collected through a set of questionnaires completed on a PC or online. For information on the conception and the background of the MoMo-PA-Questionnaire (MoMo-AFB) see Schmidt et al. (Schmidt et al., 2016). The reliability and validity of the MoMo-AFB are comparable to other international questionnaires (Jekauc et al., 2013).

Demographic information

Participants were asked for their sex and date of birth. The completed years of life on the day of the examination were used as the participant's age in years.

Pain

Self-reported pain in the last three months prior to the survey was captured by questionnaire. To ensure comparability with data from previous surveys, the questions about pain were adopted from the KiGGS Wave 2 questionnaire (Krause et al., 2019; RKI, 2017). Participants received a list of various pain locations and indicated whether pain had occurred once, recurred, or not occurred in the past 3 months. The list of pain locations included: head, abdomen, back, ears, eyes, lower abdomen, arms/hands, legs/feet, throat, teeth, and thorax. Female participants were also asked about menstrual pain. For the analysis, the responses were dichotomized: pain occurred recurrently vs. no pain occurred or pain occurred only once (see also Krause et al., 2019).

Prevalence was reported for all pain types asked in the questionnaire, while further analysis focused on recurrent headaches, recurrent abdominal pain, and recurrent back pain.

Data selection

Due to the fact that for participants aged 4 to 10 years the questionnaire and thus the questions about pain were answered by parents, we included only data from participants aged 11 to 17 years in the analysis to avoid bias from possible parental assessment.

Physical activity

After completion of the PF/MP field tests, participants were asked to wear an accelerometer (GT3X+/wGT3X-BT, ActiGraph) on the right hip during their waking hours for the following week. Before further analyzes, the non-wear time was removed from the data using an algorithm implemented by Choi et al. (Choi et al., 2011). All days with wear time of 8 h or more after the removal of the non-wear time were considered valid days. Participants needed four or more valid weekdays and at least one valid day of the weekend to be included in the further analyzes. The average time (min/day) spent in MVPA was derived from the accelerometer for all valid data sets. Participants who averaged at least 60 min of MVPA per day were considered active according to the WHO recommendation (World Health Organization, 2020).

Data analysis

The prevalences of different types of recurrent pain were calculated as the proportion of participants with pain in relation to the total number of participants in the group of interest. The prevalence of each type of pain is reported with 95% confidence intervals (95% CI) for girls and boys separately. Logistic regression was used to test whether pain could be predicted based on sex, age, and activity status. Welch tests were used to compare the group means of the PA of participants with pain and those without pain. The Welch test has statistical power comparable to the t test when variances are equal, but unlike the latter, it is robust to unequal variances and skewed distributions (Rasch et al., 2011). This eliminates the need for a preliminary check of the test assumptions (Rasch et al., 2011). Multiple Welch tests were used to determine the differences between groups for different pain locations. Due to known differences in MVPA levels in girls and boys, the differences between participants reporting recurrent pain and those who did not were also analyzed separately for both sexes in all analyzes. The level of significance was set to

Table 4.5: Prevalence and 95% CI of recurrent pain in girls.

Pain location	N	Prevalence (in %)	95% CI (in %)
head	756	42.7*	39.2 - 46.3
menstrual pain[a]	510	41.4	37.2 - 45.7
abdomen	752	28.2*	25.1 - 31.5
back	755	26.9*	23.8 - 30.2
legs/feet	613	21.9	18.8 - 25.3
lower abdomen	614	20.0*	17.1 - 23.4
throat	614	12.7	10.3 - 15.6
arms/hands	612	8.5	6.5 - 11.0
thorax	751	5.5	4.0 - 7.3
teeth	611	5.2	3.7 - 7.3
eyes	614	4.1	2.8 - 5.9
ears	613	2.3	1.4 - 3.8

Note: *different from prevalence in boys, $p<0.05$, [a]only analyzed for girls

0.05 for all statistical analyses. The analyses were performed using R statistical software (v4.1.0, R Core Team, 2021).

Results

Prevalence of Pain

Tables 4.5 and 4.6 show the prevalence rates of the pain locations surveyed in decreasing order for girls and boys, respectively.

The prevalence rates for headache, abdominal pain, back pain, and lower abdominal pain were higher in girls than in boys. Heads, abdomens, and backs were among the most common locations of recurrent pain in both girls and boys.

Meeting the WHO PA recommendation and pain

The logistic regression model for headache ($\chi^2(2) = 13.03$, $p = 0.001$, R^2(Nagelkerke) = 0.029) was significant, and it did not improve by including age. The ORs of the final model are presented in 4.7.

Table 4.6: Prevalence and 95% CI of recurrent pain in boys.

Pain location	N	Prevalence (in %)	95% CI (in %)
head	729	28.7*	25.5 - 32.1
legs/feet	612	22.7	19.6 - 26.2
abdomen	728	20.1*	17.3 - 23.1
back	728	19.5*	16.8 - 22.5
throat	613	11.6	9.3 - 14.4
arms/hands	612	7.5	5.7 - 9.9
thorax	724	5.1	3.7 - 7.0
teeth	612	4.7	3.3 - 6.7
ears	614	2.1	1.2 - 3.6
eyes	614	3.4	2.2 - 5.2
lower abdomen	708	1.6*	0.9 - 3.0

Note: *different from prevalence in girls, $p<0.05$

Table 4.7: Logistic regression model for recurrent headache.

	OR (95% CI)	*p*
(Intercept)	0.21 (0.11 - 0.39)	<0.001
Sex		
Male	Ref.	
Female	1.54 (1.09 - 2.18)	0.014
Meeting the recommendation		
Yes	Ref.	
No	2.06 (1.1 - 4.17)	0.033

Pain and physical activity

In boys, Welch tests did not show significant differences in device-based MVPA between those who reported recurrent headaches and those who did not (M_{diff}(95% CI) = 2.4(-2.7, 7.4) min, t(157.75) = 0.93, p = 0.355). There were also no differences between the boys that reported recurrent abdominal pain (M_{diff}(95% CI) = 4.5(-0.7, 9.7) min, t(95.13) = 1.72, p = 0.088) or back pain (M_{diff}(95% CI) = 3.0(-3.5, 9.5) min, t(76.1) = 0.92, p = 0.359) and those who did not.

Girls who reported recurrent headaches in the last three months averaged 4.7 min (95% CI [0.74, 8.66], t(297.29) = 2.33, p = 0.020) less MVPA than girls who reported having no headaches. Among girls who reported recurrent back pain, MVPA was 5.8 min (95% CI [1.58, 10.04]) lower on average (t(156.63) = 2.71, $p = 0.007$). For abdominal pain, the difference in device-based MVPA was not significant (M_{diff}(95% CI) = -1.3(-5.5, 3.0) min, t(171) = -0.58, $p = 0.561$).

Discussion

The present study aimed to describe the prevalence of recurrent pain in a German sample of children aged 11–17 years and to assess whether PA is associated with the occurrence of recurrent pain in children and adolescents.

We found differences between girls and boys in the prevalence of recurrent pain in several locations. Recurrent pain was observed more frequently in girls than in boys for headaches, abdominal pain, back pain, and lower abdominal pain. The most pronounced difference observed was for headaches. The analysis showed increased odds of recurrent headaches if the analyzed participant was a girl or if the participant failed to achieve the recommended average of 60 min of MVPA per day. We only found reduced PA levels in girls reporting recurrent pain, but not in boys.

For the most part, the prevalence observed in the present study did not differ from that reported in KiGGS Wave 2 (Krause et al., 2019). Only the prevalence of recurrent abdominal pain in girls' pain was higher (KiGGS Wave 2: 34.5%, 95% CI [31.9, 37.2]) than in the present study (MoMo Wave 3: 28.2%, 95% CI [25.1, 31.5]). Regarding this, we have to keep in mind that the survey in the KiGGS study was supplemented by medical examinations that do not require physical exertion on the part of the participant, while a considerable part of MoMo consists of motor test tasks. Therefore, it is possible for those, especially girls with acute complaints due to menstrual or abdominal pain, to refrain from participating in the latter. All in all, the prevalence of recurrent headaches and back pain in children and adolescents in Germany seems to remain constant on a high level over the last 5 to 10 years.

Especially with regard to recurrent headaches, it seems important to take action against the high prevalence, as previous studies have shown that headaches in adolescents leads to significant impairments in HRQoL (Hunfeld et al., 2001; Philipp et al., 2019). The fact that recurrent headaches were the most frequently cited pain in both sexes in the present data underscores the urgency of action. At the same time, the current figures indicate that either no steps have been initiated so far or that previous steps have not led to an improvement compared with the figures from KiGGS Wave 2 (2014–2017).

The Norwegian HUNT study found that recurrent headaches were associated with an unfavorable lifestyle among adolescents. The study addressed being overweight and low PA, among other factors (Robberstad et al., 2010). Their analysis showed an elevated OR of recurrent headaches for overweight (OR = 1.4, 95% CI [1.2, 1.6], $p < 0.001$) and low PA (OR = 1.2, 95% CI [1.1, 1.4], p= 0.002) adolescents (Robberstad et al., 2010). The association with being overweight was not tested in the current analysis, but higher odds were also found for the low-active group (OR (low PA) = 2.06, 95% CI [1.1, 4.17], p = 0.001). Different definitions of the threshold for low activity or the underlying metric probably explain the different magnitudes, but the direction of the effect shows a consistent picture that PA could lower the odds of recurrent headaches. The association of headaches with an unhealthy lifestyle has also been observed in other studies (Hagen et al., 2018; Milde-Busch et al., 2010; Queiroz et al., 2009). The lack of PA was often used as part of an expression of an unhealthy lifestyle. Therefore, the lack of PA showed an increased risk of migraines (OR = 4.2, 95% CI [2.2, 7.9]) and tension-type headaches (OR = 1.7, 95% CI [1.1, 2.7]) (Milde-Busch et al., 2010). In addition, social stress factors such as family conflicts, school, or bullying experiences have also been identified as possible causes of headaches (Sansone and Sansone, 2008; Straube et al., 2013). The current results underline the importance of promoting a healthy lifestyle in children and adolescents, including adequate levels of physical activity. In addition, further steps may be also beneficial, e. g., to reduce stress in the family or at school.

The difference in the prevalences of recurrent pain between girls and boys that was found in our analyses is in line with the results of KiGGS (Krause et al., 2017; Krause et al., 2019) and several international studies (Gobina et al., 2015; Philipp et al., 2019; Torres-Ferrus et al., 2019). Various reasons are discussed as explanations. On the one hand, it is assumed that girls perceive their bodies differently than boys, and that they are more sensitive and more willing to communicate their feelings (Moré, 2007). On the other hand, different pain processing in the brain and hormonal differences could play a role (de Leeuw et al., 2006; Vincent and Tracey, 2008).

In our results, we found lower MVPA in girls with recurrent headaches or back pain compared with those who reported no pain. This suggests that the presence of pain may have a negative impact on PA, which in turn would support the findings of another population-based survey that also reported reduced MVPA in the presence of pain (Swain et al., 2016).

In summary, the results confirm the high prevalence rates reported in previous surveys of German youth. Logistic regression shows that only a small part of the variance in our sample can be explained by the factors examined. At the same time, it should be kept in mind that both physical activity and pain are very complex constructs. However, the results show a consistent picture and indicate that being female and having a low activity status are associated with a higher prevalence of recurrent pain, especially headaches and abdominal pain.

One strength of the MoMo study data set is its representative sample (Kurth et al., 2008; Woll et al., 2017a). Although data collection in the current wave ended prematurely due to the pandemic, data was collected in about two-thirds of the test sites according to the pre-established protocol.

On the other hand, the MoMo study uses proven methods on the different waves, which allows for comparability between the different waves of the study.

Nevertheless, there are some limitations to consider. The representativeness of the sample is compromised by the discontinuation of the study due to the pandemic. Due to the fact that the results of the study are on the same level as those of KiGGS Wave 2, it can be assumed that the impact due to early termination is manageable. Pain data were collected by questionnaire, and therefore may be biased by recall error or incorrect information due to social desirability (Jekauc et al., 2014; Kahlert and Brand, 2011; Müller et al., 2010). In particular, with regard to the questions on pain, it can be seen that the recall period of three months is relatively long. To prevent misperception of health statuses by parents from becoming a problem, only data from children 11 years and older were analyzed. From this age, the participants fill out the questionnaire themselves. In addition, it is possible that children and adolescents currently suffering from pain may not participate in the study at all or refuse to wear the accelerometer, resulting in exclusion from the analysis due to missing data.

Last but not least, based on the cross-sectional data, we can only make statements about the correlations, but cannot draw conclusions about causal effects.

Conclusion

The prevalence of pain, especially of recurrent headaches, abdominal pain, and back pain, remains at a high level in girls as well as in boys in Germany, and therefore underscores the need for interventions to improve the health situation of children and adolescents. First, more research is needed to find the reasons for such a high pain prevalence while also considering sex differences in frequencies and types of pain. Lifestyle recommendations play an important role in the treatment and prevention of pain in childhood, and especially in adolescence Raucci et al., 2020. Therefore, it is important to further investigate the effects of lifestyle factors, such as PA, to gain a better understanding and therefore make more targeted recommendations. This also needs longitudinal data to investigate causal effects between PA and pain. Furthermore, it should be considered that PA, in addition to the presumed preventive effect against pain, can also be a trigger of the same. Finally, the presence of pain can influence PA levels, and thus should therefore be considered when assessing PA to avoid bias.

The descriptions of physical activity, physical health and the correlation between the two constructs in Paper II referred in the previous sections to a single measurement point or a cross-sectional view. In this way, for example, a condition at one point in time or differences between girls and adolescents or between age groups can be examined and presented. The next section deals with development over time. Here, too, the two constructs are first presented separately and then the relationship between the two constructs is analyzed, taking into account the factor of time.

4.4 Physical activity over the course of childhood and adolescence

The following section presents the development of physical activity over time using data from the MoMo longitudinal study. The longitudinal sample used for the following evaluations is described in detail in section 3.2.2.

4.4.1 Overall physical activity

About 60% of the subjects reported a lower number of active days at the third survey compared to the first. The percentage was slightly higher for the males (61.4%) than the females (57.0 %). Considering the age at the first survey, the share of subjects with a decrease in active days is highest in the youngest group (4-5 y.: 68.9 %), followed by group two (6-10 y.: 62.8 %), and three (11-13 y.: 44.3 %). The subjects of the oldest group showed the lowest share of decreasers by 39.3 %.

Comparing the reported shares of subjects that decrease their PA in form of days with at least 60 min of MVPA with the distribution over the age as described earlier in this section, it appears that the groups with a higher share of decreasers are those with higher initial values. Male participants reported a higher number than females, the younger subjects reported more active days than the older ones. In other words, in groups with higher potential for a decrease more decreasers are observed.

Individual development generally follows the distribution that would be expected based on the distribution across age groups. The mean difference in active days observed between the youngest age group and the oldest age group in the cross-sectional sample was -1.42 [-1.55, -1.29] days. The age difference between the two groups (4-5 y. vs. 14-17 y.) is comparable to the time between the first and the third measure in the longitudinal sample (11.5 $\pm$ 0.7 y.). The mean difference in active days observed in the youngest group at base was -1.58 [-1.59, -1.57] days from the first to the third survey. The group that was between six and ten years old at the first survey reduced their active days on average by -1.10 [-1.11, -1.09] days until the third survey. The third groups mean value was also lower at the third survey compared to the first, but the margin was very small (-0.07 [-0.09, -0.05] days). Finally, the oldest group at the baseline survey is the only group whose mean was higher for the third survey (0.32 [0.30, 0.35] days).

Table 4.8: Mean Differences with 95%-CI in weekly minutes of PA in sport club by sex and age

	female	male
4-5 y.	76.74 [75.55, 77.93]	104.27 [102.66, 105.88]
6-10 y.	6.97 [6.00, 7.94]	35.10 [33.72, 36.48]
11-13 y.	-24.92 [-27.10, -22.74]	-47.27 [-50.67, -43.87]
14-17 y.	-49.33 [-52.09, -46.58]	-74.58 [-78.84, -70.32]

4.4.2 Leisure time sporting activity within a sport club

36.1 % of the participants that participated in the first three waves reported a decrease in the amount of PA in a sport club from the first to the third survey, while 35.3 % reported an increase over the same period. The mean difference for the whole sample was 23.6 [23.4, 23.9] min per week. The mean difference of the female subjects (17.7 [17.3, 18.1] min) was significant lower than the mean difference of the males (31.1 [30.6, 31.7] min).

If the group is divided based on age at the first measurement point, the mean difference for the 4-5 year olds (88.6 [87.9, 89.3] min) and the 6-10 year olds (19.8 [19.2, 20.3] min) is positive, which means that on average the PA in the sports club was higher at the last measurement point. In contrast, the mean difference for 11-13 year olds (-35.0 [-36.4, -33.6] min) and 14-17 year olds (-59.7 [-61.4, -58.0] min) is negative, meaning that activity in the sports club was lower at the last measurement point. The directions of the mean deviation are the same for the male and female participants, the absolute level of the differences is higher for the male participants than for their female counterparts, as is the case for the group as a whole. Table 4.8 shows the mean difference by age and sex.

4.4.3 Leisure time sporting activity outside of a sport club

The mean difference in reported sport activity during leisure time from T1 to T3 was 17.46 [17.23, 17.68] min. The mean differences do not differ between female (17.56 [17.19, 17.92] min) and male (17.33 [16.77, 17.88] min) study participants. But when data is stratified by age for both sexes, differences can be observed in three of the for age groups. While all mean differences are still positive, which means that the leisure time PA reported at the last survey was higher on average than at baseline, the absolute values of the differences vary over the groups. Mean differences with confidence intervals are shown in table 4.9.

Table 4.9: Mean Differences with 95%-CI in weekly minutes of leisure time sporting activity by sex and age

	female	male
4-5 y.	20.59 [19.53, 21.65]	3.62 [2.37, 4.87]
6-10 y.	14.80 [13.84, 15.76]	25.33 [23.81, 26.85]
11-13 y.	25.18 [22.42, 27.94]	19.86 [15.65, 24.07]
14-17 y.	10.08 [7.32, 12.84]	23.31 [18.69, 27.93]

4.5 Physical health over the curse of childhood and adolescents

Physical health is a broad topic. In the following sections a selection of indicators from the MoMo data are used to illustrate the development over time. The chosen aspects of physical health are the weight status with a special focus on overweight, cardiorespiratory fitness as marker of the health of the cardiovascular system, the self-rated health status, and the self-reported recurrent pain especially headache.

4.5.1 Body composition and overweight

Looking at the progression of BMI and its percentiles in children and adolescents with increasing age, as shown by Krohmeyer-Hauschild Kromeyer-Hauschild et al., 2001, for example, it can be assumed that the BMI of the participants increases over the years. For example, a boy in Germany has a BMI of 15.4 kg/m^2 at the fiftieth percentile at the age of five, while at the age of 15 a value of 19.9 kg/m^2 is given for the fiftieth percentile Kromeyer-Hauschild et al., 2001. Part of the variance can be attributed to the physical development that takes place in the target population between the surveys. Depending on the age at the time of first participation, the recorded period covers different parts of physical development. The younger a participant was at baseline, the greater the expected increase in height and weight and the associated change in BMI. For participants who were almost or fully grown at the time of their first examination, only minor changes in BMI are to be expected, which can be attributed to the growth process.

At baseline, 85 % of the longitudinal sample were classified as normal weight, while 8% were classified as underweight, and 7 % as overweight. 78 % of the normal weight subjects stayed in that category over time, but 17 % were classified as overweight at Wave 2 (T3: 2014-2017). In the overweight subjects, approximately 74 % remained in that category, while nearly 25 % became normal weight. At Wave 2 (T3), 74 % of the subjects were classified as normal weight, 20 % as overweight, and 6 % as underweight. This means the proportion of overweight people almost tripled from the baseline to wave 2.

4.5.2 Self-rated health

In the baseline survey, 42.3 % of the longitudinal sample rated their general state of health as very good, 53.7 % as good and 4.6 % as fair or worse. In wave 2 (T3), 31.3 % stated that their general state of health was very good, while 58.2 % rated it as good and 9.8 % as fair or worse. Around half of the participants (50.8 %) who took part at both measurement times rated their general state of health identically at baseline and in wave 2. 16.7 % rated their general state of health at wave 2 as better than at baseline, for 31.4 % it was the other way around, they rated their general state of health at baseline as better.

4.5.3 Cardiorespiratory fitness

As showed in chapter 5, the performance in watt at 170 bpm rise with age and levels of at the beginning of adulthood. Because of that, the differences between the performance at the baseline and the performance at Wave 2 (T3) is greater in those participants who were younger at baseline. The mean difference is 66.4 watt with a standard deviation of 46 watt, differences range from −46 watt to 240 watt. Only 32.8 % of the longitudinal sample completed the endurance testing at both surveys, baseline and Wave 2. The mean difference in the relative performance between baseline and Wave 2 (T3) was not significant ($t(1671.4) = 0.417$, $p = .677$).

4.5.4 Recurrent headache

In the longitudinal sample 28.8 % reported recurrent headaches at baseline. The frequency is slightly higher as expected based on the numbers of the cross-sectional sample. In the Wave 2 survey 43.8 % of the participants in the longitudinal arm of MoMo reported recurrent headaches over the past three months. 39.8 % reported no recurrent headaches either at the baseline or at T3. 31.3 % reported recurrent headaches only at T3, while 12.1 % reported recurrent headaches only at the baseline. The remaining 16.8 % reported recurrent headaches at both surveys, the baseline and T3. 56.0 % of the participants who reported no recurrent headaches at baseline, did also report no recurrent headaches at T3. Of those who stated in the baseline survey that they had had repeated headaches in the previous three months, 58.2 % stated this again at T3.

4.6 Association between physical activity and physical health over time

The relationship between physical activity and physical health over time is the main objective of Paper III *Association between physical activity and physical health in German children and adolescents – results from the MoMo Longitudinal Study*. The paper analyzes the effect of the participants sporting activity over time on physical health parameters at follow-up. Therefore, participants with different activity patterns (consistently high activity, increasing activity, decreasing activity, consistently low activity) will be compared on CRF, body composition, and reported pain.

Association between physical activity and physical health in German children and adolescents - results from the MoMo Longitudinal Study

Slightly modified version of Paper III submitted on 10th October 2024 and accepted for publication in *BMC Public Health*.

Abstract: Adequate physical activity is essential to maintain and improve physical health, including in adolescents and young adults. A significant part of physical activity is sports activity. However, few longitudinal studies cover the transition from adolescence to early adulthood. Therefore, the aim is to assess how the maintenance or a change in sports activity during this transition relates to physical fitness, BMI, and recurrent pain. Data of 947 adolescents aged 11 - 17 years (53 % girls) from the Momo baseline (2003 - 2006) that were followed up at MoMo Wave 1 (2009 - 2012) were used. Sports activity was categorized ($>$ 240 min/wk sports activity vs. $\leq$ 240 min/wk) and change patterns over time were calculated (maintain active, maintain passive, increasing, decreasing). Separate ANOVAs were used to analyze the difference in cardiorespiratory fitness (CRF), push-ups, standing long jump, and BMI at wave 1 between the sports activity groups. A logistic regression was used to assess the difference in the occurrence of recurrent headaches at wave 1 between groups. All analyses were controlled for sex and age, and post-Hoc-Tests were conducted where applicable. The analysis revealed significant differences between the activity groups at the follow-up for CRF ($F(3, 502) = 13.65$, $p < .001$), push-ups ($F(3, 599) = 10.45$, $p < .001$), and standing long jump ($F(3, 601) = 12.03$, $p < .001$). There were no significant differences in BMI between the groups ($F(3, 610) = 0.08$, $p = .970$). The odds for the low active group were two times higher to report recurrent headaches at the second measure compared to the consistently active ones. Participating in sports regularly from adolescence to early adulthood is associated with the strongest health benefits. Nevertheless, those who were less active initially but increased their sports activity had similar health outcomes, highlighting the importance of sports activity as part of a healthy lifestyle in young adulthood.

Keywords: cardiorespiratory fitness, body composition, recurrent headache

Introduction

Adequate levels of physical activity (PA) are essential for improving or maintaining health (Janssen and Leblanc, 2010; Poitras et al., 2016). As the foundation for health and PA is laid in childhood and adolescence, it is crucial to examine this relationship early on.

As part of a systematic review, a group of 27 experts in physical activity research with children and adolescents identified 11 relevant indicators to assess health in this population. Seven of these were categorized as critical or primary and four others as important or secondary (Poitras et al., 2016). For this study, we looked at body composition, cardiorespiratory fitness (CRF), musculoskeletal health, and pain which are proxy measures for three critical indicators body composition, physical fitness, and harms.

Overweight and obesity are not only the leading risk factors in the adult population but are also a major concern for children and adolescents. Adolescent overweight and obesity are associated with an increased risk of chronic diseases, including type 2 diabetes later in life (Abarca-Gómez et al., 2017). Although weight loss and maintenance can be challenging (MacLean et al., 2015), preventing excessive weight gain during childhood and adolescence is crucial. Data from the International Children's Accelerometer Database (ICAD) showed associations between moderate-to-vigorous physical activity (MVPA) and lower BMI and waist circumference (WC) z-scores that were particularly pronounced at higher percentiles, suggesting that promoting MVPA could reduce the number of children and adolescents in the upper tail of the BMI and WC distributions (Mitchell et al., 2017). Given that overweight and obese children or adolescents often continue to struggle with weight into adulthood (Herman et al., 2009), early intervention is essential.

Physical fitness can be seen as a comprehensive assessment of numerous, if not all, bodily functions, including the musculoskeletal and cardiorespiratory systems, among others. These functions play an essential role in the execution of daily tasks, PA, or physical exercises. This makes PF itself an important health marker (Ortega et al., 2008). An aspect of PF is CRF, which was an important health resource for the prevention and management of non-communicable diseases such as cardiovascular disease (Pandey et al., 2016), cancer (Schmid and Leitzmann, 2015), and diabetes mellitus (Zaccardi et al., 2015). It also contributed significantly to reducing the risk of premature mortality (Schmid and Leitzmann, 2015). A recently published study of Icelandic children revealed that adolescence was a significant milestone in the development of CRF. The findings advocated early measures to improve CRF in later life (Ingvarsdottir et al., 2024). Another aspect of PF is muscular fitness (MF), which refers to the ability to exert force against resistance. MF was influenced by muscle size, fiber activation, and group coordination, making it difficult to measure with a single test. Important health-related components included maximal, explosive, endurance, and isokinetic strength (Ortega et al., 2008). It played an important role in daily activities, exercise performance, and disease prevention (Wolfe, 2006).

Recurrent pain was not only a problem in adults; it also affected children and adolescents (Nieswand et al., 2019, 2020; Perquin et al., 2000; Roth-Isigkeit et al., 2003). It can significantly disrupt daily activities, leading to increased school absences and reduced participation in sports or social events (Nieswand et al., 2020; Palermo, 2000). In addition, recurrent pain affected well-being, which could lead to a reduced quality of life (HRQoL) and emotional challenges such as anxiety and depression (Krause and Mauz, 2018; Krause et al., 2017). Although scientific evidence was limited, PA, especially aerobic exercises, was often recommended for migraine patients (Busch and Gaul, 2008; Hammond and Colman, 2020).

Childhood and adolescence are pivotal stages in life, marked by significant physiological and psychological changes. During these stages of their life, people form lifestyle habits and behaviors, both healthy and unhealthy, that can shape their adult lives and overall health (van Sluijs et al., 2021). For example, the transition from secondary school to young adulthood is an important developmental phase in which several serious changes occur simultaneously and within a short period (Jindal-Snape and Rienties, 2016; Jindal-Snape et al., 2020). Recent comprehensive studies have explored the relationship between adolescent physical activity and its immediate and long-term effects on health (Ortega et al., 2008).

To be able to map the changes during such transitions, studies are needed that examine the same participants at different points in time. Unfortunately, these longitudinal analyses are precisely the studies whose importance is repeatedly emphasized and of which there are still too few (Janssen and Leblanc, 2010; Poitras et al., 2016). Those studies are costly and resource-intensive, especially on a large scale, which is one of the possible reasons for their scarcity.

The purpose of this article was to assess the influence of maintaining, increasing, or decreasing sports levels on different physical health indicators over 5 years in adolescents in transition to adulthood using data from a national longitudinal study from Germany.

Methods

Study design and participants

Data from the MoMo longitudinal study were used this analysis. MoMo (Bös, 2009; Kurth et al., 2008; Woll et al., 2017b) was initiated in 2003 as an in-depth module of the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) which is part of the German health monitoring run by the Robert Koch-Institute (RKI). Similar to KiGGS, MoMo combined a cross-sectional survey at each wave (T1: 2003-2006, T2: 2009-2012, T3: 2014-2017,T4: 2018-2022), and a longitudinal sample that is followed up since the baseline measurement (Bös, 2009; Kurth et al., 2008; Woll et al., 2017b). At baseline, a total of 17,641 children and adolescents aged 0 to 17 years with primary residence in Germany participated in the representative KiGGS-Study. The study population was selected using a stratified multistage probability sample with three evaluation levels. In the first step, 167 municipalities were selected from the inventory of municipalities in Germany. Then a stratified sample of participants aged 0 to 17 years was randomly selected from the register of the municipalities. A detailed description of the sampling procedure is given by Kurth et al. (Kurth et al., 2008). Finally, a subsample of KiGGS was elected to participate in MoMo. The studies were approved by the Charité/Universitätsmedizin Berlin Ethics Committee and were performed according to the Declaration of Helsinki.

Between 2003 and 2006, 4,529 children and adolescents aged 4 to 17 years from 167 cities across all states of Germany participated in the MoMo baseline. For the following analysis, only participants aged between 11 and 17 years at baseline that also completed the measurement at Wave 1 (T2: 2009-2012) were selected (n = 947).

Variables

Anthropometric measures

Standing height was assessed using a stadiometer (Seca, Hamburg, Germany) with an accuracy of 0.1 cm. Body mass was determined using an electronic scale (Seca, Hamburg, Germany) with an accuracy of 0.1 kg. Body mass index (BMI) was calculated by dividing body mass by the square of height.

Cardiorespiratory fitness

Cardiorespiratory fitness was evaluated using the Physical Working Capacity 170 (PWC170) cycle ergometry test, performed on a stationary bicycle (Ergosana, Germany). Initial workload was calculated based on body mass and incrementally increased every 2 minutes. Further information on the protocol can be found elsewhere (Bös, 2009). Participants followed this progressive protocol until their heart rate exceeded 190 beats/min for at least 15 seconds, the pedaling rate dropped below 50 rpm for at least 20 seconds, or they decided to stop due to exhaustion. Heart rate was recorded immediately before each workload increase. The power output (in watts) at a heart rate of 170 beats per minute (PWC170) was determined by interpolating or extrapolating the measured data in Excel.

Musculoskeletal fitness

The MoMo test battery assesses various aspects of physical fitness (Worth et al., 2015), among others lower extremity explosive strength and upper extremity muscular endurance. Lower extremity explosive strength is evaluated through the standing long jump task. Participants attempt to jump as far forward as possible from a standing position without losing balance, and the better value is recorded.

Upper extremity muscular strength is measured using a standardized form of push-ups. In this test, the participant starts in a prone position, smoothly transitions into the push-up position, lifts one hand off the ground, touches the other hand, and returns to the starting position. The repetition ends by bringing the hands together behind the back while still in the prone position. Participants have 40 seconds to complete as many correct repetitions as possible.

Self-reported pain

Participants self-reported pain experienced in the three months prior to the survey using a questionnaire. They were presented with a list of various pain locations and indicated whether the pain had occurred once, recurred, or not occurred during that period. The pain locations included the head, abdomen, back, ears, eyes, lower abdomen, arms/hands, legs/feet, throat, teeth, and thorax. Female participants were also asked about menstrual pain. In the current study only headache was included as a measure of physical pain as previous analysis had shown that it has the highest prevalence in the study population (Kolb et al., 2022; Krause et al., 2017; Krause et al., 2019). For the analysis, the responses were categorized into two groups: pain occurring recurrently versus no pain or pain occurring only once.

Physical activity
Physical activity in different settings (sport club, leisure time, school, everyday life) was assessed via questionnaire. In terms of reliability and validity, the MoMo-PAQ is similar to other internationally published physical activity questionnaires for adolescents (Jekauc et al., 2013). In this study the total minutes of physical education, extracurricular sport activity in school, leisure time sport activity, and club sport per week were summed up and used as measure of physical activity.

Data analysis
Data analysis was focus on differences based on the activity level of the participants. Therefore, the sample was grouped based on the sport index, and participants were either categorized as high active if they exercised for at least 240 minutes per week, or as low active if their total activity was below this threshold. The chosen threshold divides the sample in two even groups

For the analysis of the development of activity behavior on health at the second measurement point, the activity categories of both measurements were combined. This resulted in four groups: the consistently high active, the consistently low active, as well as the two switcher groups, the increasers and the decreasers. To analyze the difference in BMI, CRF, and muscoloskeletal fitness at the second time point between the sports activity groups, we used separate ANOVAs for each outcome with age at baseline and gender included as covariates. Pairwise comparisons of means were tested using the tukey method. For the effect of PA development on recurrent headache, logistic regression with the PA group as factor was used as the outcome is dichotomous. The consistently active group was used as reference, and Wald statistics was used to check for significant differences between the estimates of the sport activity group.

All analyzes were performed in R (R Core Team, 2021) and the level of significance was set at .05 for all statistical analyzes.

Results

Participants
The sample consists of a total of 947 (53 % female) subjects that participated in baseline (T1: 2003-2006) and wave 1 (T2: 2009-2012). Sex, mean age at baseline, and total sport minutes at baseline stratified by PA group are presented in table 4.10.

Physical health at second measure by activity group
The ANOVA revealed significant differences between the groups in CRF at the second measure ($F(3,502) = 13.65$, $p < .001$). The *post-hoc* analysis showed higher scores for the consistently

Table 4.10: Sample description stratified by activity group

	high active[A] (N = 233)	low active[B] (N = 367)	decreaser[C] (N = 247)	increaser[D] (N = 100)	Overall (N = 947)
sex					
male	155 (66.5 %)	116 (31.6 %)	124 (50.2 %)	52 (52.0 %)	447 (47.2 %)
female	78 (33.5 %)	251 (68.4 %)	123 (49.8 %)	48 (48.0 %)	500 (52.8 %)
age at baseline (in years)					
Mean (SD)	13.8 (1.94)	14.6 (1.97)	14.1 (1.94)	13.5 (1.99)	14.2 (1.99)
Sport Index[1] at baseline (min/week)					
Mean (SD)	438 (176)	130 (58.6)	407 (182)	157 (53.4)	281 (196)
Difference Sport Index: T1 - T2 (min/week)					
Mean (SD)	8 (230)	-44 (84)	-310 (190)	241 (198)	-71 (237)

[1]Sport Index (SI): total sum of leisure time sports activity within sport club, leisure time sports activity outside sport club, sports activity in age specific setting (school, kindergarten, work)
[A]high active: SI (T1) $>$ 240 min/week & SI (T2) $>$ 240 min/week
[B]low active: SI (T1) $\leq$ 240 min/week & SI (T2) $\leq$ 240 min/week
[C]decreaser: SI (T1) $>$ 240 min/week & SI (T2) $\leq$ 240 min/week
[D]increaser: SI (T1) $\leq$ 240 min/week & SI (T2) $>$ 240 min/week

high active group compared to the consistently low active group and the group that decreased their activity between the measures. Moreover, the consistently low active group had a significantly lower score than any other group at the second measurement (Table 4.11).

We found significant differences in Push-ups between the groups ($F(3,599) = 10.45$, $p < .001$). Tukey *post-hoc* tests indicate that the consistently high active group got significantly higher scores than the decreasers and the low active group. There were no significant differences between the decreasers, the increasers, and the low actives (Table 4.11).

The ANOVA for the standing long jump task showed significant differences between the group means ($F(3,601) = 12.03$, $p < .001$). The *post-hoc* analysis indicates that the consistently high active group achieved better scores than any other group and the "decreasers" performed better than the "low actives".

The ANOVA for BMI showed no significant differences between the activity groups ($F(3,610) = 0.08$, $p = .970$).

The logistic regression for headache showed a significant overall effect for the activity groups ($X^2 = 17.2$, $df = 3$, $p < .001$). The odds ratio (OR) (CI95%) of the consistently low active group was 2.1 (1.4, 3.2) compared to the consistently high active group for reporting recurrent headaches

Table 4.11: Estimated Means of health outcomes at second measure by activity group.

	high active[A] n = 233	low active[B] n = 367	decreasers[C] n = 247	increasers[D] n = 100	Total n = 947
Endurance	**62.48[a,b] (29.25)**	**43.17[a,c,d] (28.28)**	**51.34[b,d] (30.73)**	**59.35[c] (29.16)**	52.09 (30.24)
PushUps	**59.65[e,f] (27.01)**	**42.99[e] (28.94)**	**49.27[f] (27.81)**	51.05 (31.74)	49.99 (29.12)
Standing long jump	**59.86[g,h,i] (27.36)**	**41.65[h,j] (27.58)**	**50.92[i,j] (27.89)**	**49.05[g] (29.51)**	49.74 (28.65)
BMI	23.17 (3.28)	23.28 (4.86)	23.31 (4.49)	23.27 (3.75)	23.26 (4.26)

Endurance, Push-Ups & Standing long jump are reported in mean (SD) percentile score. BMI is calculated as mean (SD) weight in kilograms divided by height in meters squared. Bold indicates significant differences by post-hoc analyses between groups with the same superscript letters.
[A]high active: SI (T1) $>$ 240 min/week & SI (T2) $>$ 240 min/week
[B]low active: SI (T1) $\leq$ 240 min/week & SI (T2) $\leq$ 240 min/week
[C]decreaser: SI (T1) $>$ 240 min/week & SI (T2) $\leq$ 240 min/week
[D]increaser: SI (T1) $\leq$ 240 min/week & SI (T2) $>$ 240 min/week

at the follow-up. The OR for the group that increased the PA was 2.5 (1.5, 4.3) and 1.9 (1.3, 3.0) for the group that decreased the PA respectively, compared to the consistently high active group.

Discussion

The aim of this study was to investigate whether maintaining, decreasing or increasing activity levels over a five-year period during the transition from adolescence to adulthood has an impact on selected markers of physical health. CRF, MF, body composition, and recurrent pain were used as indicators of physical health.

CRF scores of the high actives were higher than those of the low actives and decreasers, but not higher than those of the increasers. Parts of this result are in contrast to those from other studies. Leppaenen et al. found greater VPA and/or MVPA measured by accelerometer at baseline were associated with better CRF a year later (Leppänen et al., 2017). Buergi et al. report favourable association of baseline PA and CRF in preschoolers (Bürgi et al., 2011-07). While this is adequate for the high actives compared to the low actives, the decreasers that had higher PA levels at the first measurement showed worse CRF scores at the follow-up compared to the actives while the increasers' CRF scores who had lower PA levels at baseline did not differ significantly from those of the active group. However, it must be borne in mind that the interval between the two measurement points in the present study was around five years, whereas in the study of Leppaenen et al. it was only one year. The positive correlation between higher PA and CRF does not appear to exist over the five-year period. The current PA level appears to be more important here, as the CRF of the active group in the study was not significantly better than the performance of those who increased their PA level between the measurements. In contrast, the CRF level of the increasers was significantly higher than that of the low active, which shows that an increase in PA can lead to an improvement in endurance performance. A study by Kallio et al. found that even minor increases in PA resulted in a lower cardiometabolic risk later (Kallio et al., 2021-04). The study of Leppaenen et al. shows significant correlations with CRF only for MVPA and VPA. The study of Buergi et al. indicated that only baseline VPA is associated with an improvement in CRF (Bürgi et al., 2011-07). This suggests that the intensity of PA plays a role for the effect. No accelerometers were used in the current study; PA was recorded by questionnaire. The sport index used in the current study includes activity in sports clubs and sport in leisure time. It can be assumed that these activities tend to have a higher intensity than everyday activities, which fits in with the results of the studies of Leppaenen and Buergi.

From the area of motor fitness, push-ups were used in the present study as an indicator of upper limb strength and standing long jump for lower limb strength. With regard to the push-ups, it was found that the performance of the high active participants was better than that of the decreasers and the low active group, but not significantly higher than the performance of the increasers. The mean percentile score of the increasers was higher compared to the decreasers and low active group, but the difference was not significant. With regard to the standing long jump, the high active group performed significantly better than any of the other groups. In addition, the decreasers were significant better than the low active group. The results of the current study match those in the literature. Baquet et al. report that a consistently high level of physical activity is associated with better physical fitness (Baquet et al., 2006). A recent study of Swedish children aged four and nine showed that the children who fulfilled the physical activity recommendations at both times had better fitness at the second measurement point (Tigerstrand Grevnerts et al., 2024).

As far as BMI is concerned, no differences were found between the activity groups in the current study. One possible factor here is the relatively long period of around five years between the surveys. During this time, other factors besides the PA can also influence the development of the BMI. Another point is the fact that PA or physical training, e.g., to improve athletic performance, stimulates muscle growth and thus leads to an increase in body weight, which has a negative effect on the BMI value. To overcome this weakness of the BMI, other methods are used to assess body composition, which take into account whether the weight is due to body fat or lean mass. The aforementioned study by Leppaenen also showed no effect of PA on BMI. However, the authors found a weak negative correlation between PA and FFMI (Fat Free Mass Index) or percentage body fat (Leppänen et al., 2017). This is consistent with the results of a study by Metcalf et al. who investigated the effect of achieving a government-recommended level of physical activity on obesity-related parameters. The study showed that children with physical activity above the recommended 3 METs achieved an improvement in their metabolic health, but no change in BMI or fatness (Metcalf et al., 2008). In contrast, a systematic review concludes that the studies analysed support the hypothesis that a higher level of habitual activity counteracts the development of obesity (Jiménez-Pavón et al., 2010). However, the authors note that much of the evidence comes from cross-sectional studies and that longitudinal designs and intervention studies are necessary to be able to make statements on causality (Jiménez-Pavón et al., 2010).

Moreover, being consistently high active was associated with less self-reported recurrent headache at follow-up. The result is in line with previous cross-sectional analyses in different subsamples of the MoMo and KiGGS data (Kolb et al., 2022; Krause et al., 2017; Krause et al., 2019).

In summary, the analysis indicated that the consistently active group had a better CRF than the consistently less active group, a better MF than any other group, and was less likely to report recurrent headache than the other groups. With regard to BMI, there was no difference in mean values between the activity groups.

Together, our study aligns with the evidence for beneficial longitudinal effects of PA on physical health. Participants who were consistently active at both surveys achieved better scores in health-related measures at the follow-up. The results underline the importance of an active lifestyle from early on, but they also indicate that becoming more active can improve your physical health.

While the results of our study underline the importance of consistent PA for physical health, we know from other studies that PA declines during adolescents (Dumith et al., 2011) and from adolescents to adulthood (Corder et al., 2019). In view of this, appropriate promotion and the creation of conditions conducive to physical activity should ensure a high initial level of physical activity in childhood and, at the same time, action should be taken to minimize the decline. In addition to the question of possible factors influencing the decline, the development of suitable programs and activities to promote physical activity must therefore also be the focus of future research.

Strength and weaknesses

The analysis has some strength and weaknesses which have to be considered. The study is based on a complex sample. The sampling strategy counteracts selection effects and allows representative statements to be made. In case of the longitudinal sample, differences in re-participation rates between groups could lead to a skewed distribution and therefore reduce the generalizability of the results. But, the genuine longitudinal part of the study in which the same people are interviewed several times, enables the possibility to analyze individual trajectories and improve the understanding of the development within a subject.

The interval between measurement times in the current study is relatively long with five years between the measurements. This means that an effect need to be relatively stable and sufficiently clear in order to be recorded after that period. At the same time, the long time span offers a lot of room for possible confounding factors to influence the analyzed variables. One example of this is the BMI, which is known to be significantly influenced by dietary behavior.

In the present analysis physical activity is assessed via questionnaire. Self-reported data tends to overestimate the amount of PA. This can be avoided or reduced by using sensors. On the other hand, the analysis deals with activity in certain settings, which in turn cannot be captured by sensors. Another point that needs consideration is the type of PA that is measured. In the case of the current study an index representing the total amount of sport activity per week was used. Therefore, it can therefore be assumed that most of the PA that was taken into account was structured, planned and, possibly guided. At the same time, the types of activity carried out were not taken into account.

Conclusion

The results add to the evidence of beneficial effects of physical activity on physical health (Janssen and Leblanc, 2010; Poitras et al., 2016). Thus, they support calls for an active lifestyle to promote and maintain health, as called for by the WHO, for example (World Health Organization, 2018, 2020). The analysis suggests that staying consistently active is the most favorable option to maintain and improve physical health. It follows that not only is it important to encourage people to be more physically active, but it is also important to support those who are active to stay active. Especially in the sensitive transitional phases during childhood and adolescence, such as entering secondary school or starting vocational training or university, it is important to have programs available that fit the changed conditions. Nevertheless, the results indicate that somebody with a lower level of PA can still improve their physical health by increasing their PA.

Sections 4.4 and 4.5 described the changes in physical activity and physical health from childhood to young adulthood. The subsequent section, 4.6, undertakes a thorough examination of the interplay between these two constructs. In the discussion that follows, the results are analyzed and the research questions of the work are answered.

5 Discussion

The concluding discussion summarizes and contextualizes the results of the individual chapters. In addition, the role of physical activity in reducing negative health consequences is examined. The chapter concludes with a discussion of the strengths and weaknesses of the work and recommendations for further research in this area.

5.1 Synthesis of Findings Across Chapters

The complexity and diversity of the subject area is already apparent from the theoretical background against which the work is moving. Both core aspects, physical activity, which in turn is part of physical behavior, and health, are multidimensional constructs in themselves, the description, presentation and examination of which represent major challenges.

As a first step towards reducing this complexity, and drawing on the MoMo study, which forms the basis of this work, children and adolescents were selected as the subject of the analyses.

The next step is to reduce the two constructs. Based on the biopsychosocial model of health and disease, the concept of health can be simplified, for example, by reducing it to one of the dimensions of body, mind or environment (cf. fig 5.1). Such a dimensional approach is mentioned by Eggert (2015), among others, as a way of analyzing individual aspects in detail and then integrating the findings into a holistic system. In the present work, this approach was chosen and the focus was placed on physical health as visualized in figure 2.1. The first article of the dissertation, an overview article, then looked at the analysis of which indicators are used in research with children and adolescents to measure the physical aspects of health. We found that physical health in children and adolescents was typically expressed through measures of body composition, cardiometabolic parameters, physical fitness, and bone health (Kolb et al., 2021). At the same time, the analyses also showed that an indicator such as body composition was represented by a number of different variables. In the various studies we examined, body composition was expressed, among other things, by BMI, skinfold thickness, body fat percentage or fat-free mass (Kolb et al., 2021). On the other hand, we were also able to identify common proxy variables for the indicators. The most commonly reported proxy variables were BMI for

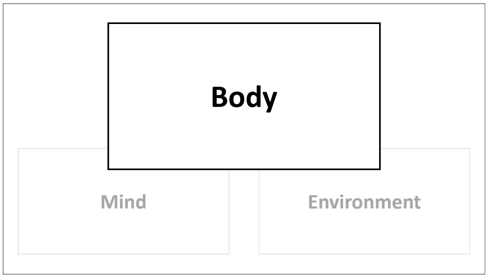


Figure 5.1: Dimensional reduction of the biopsychosocial model as used in this thesis

body composition, blood pressure for cardiovascular health, aerobic fitness for fitness, and bone mineral content for bone health (Kolb et al., 2021).

To further simplify the research question, one can try to reduce the complexity of physical activity. While the construct itself remains complex and multi-layered, a simplification can be achieved by focusing on individual aspects of physical activity, similar to the reduction of health based on the dimensions. Based on Figure 5.2, this can be done, for example, by looking at the context of the activity and considering the effects of sport in a club. Another possibility would be to examine only activities with a certain intensity, such as MVPA that is required in many recommendations.

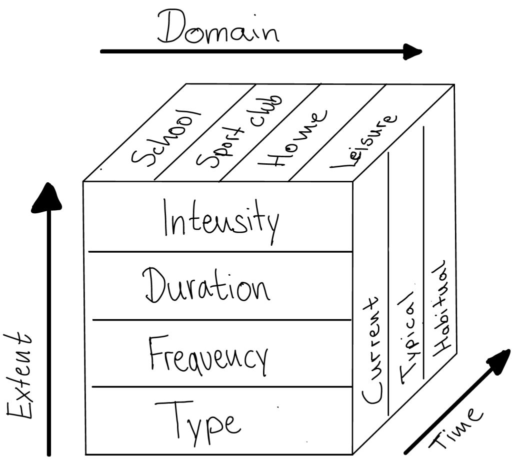


Figure 5.2: Dimensions of PA by Woll (modified and translated version, cf. Woll, 2006)

In the second article, we looked at the relationship between recurring physical pain and physical activity in a cross-sectional way. In the sample examined, recurring headaches, abdominal pain and back pain, as well as menstrual pain in female participants, were mentioned most frequently. Recurrent headaches were reported most frequently by both sexes. Among the female participants, 42.7 % (CI95: 39.2, 46.2) stated that they had recurrent headaches in the three months prior to the examination. Among the male participants, the figure was 28.7 % (25.4, 32.0). The analysis also showed that participants who did not meet the physical activity recommendation of at least 60 minutes of MVPA per day were more likely to report frequent headaches (OR = 2.1) (Kolb et al., 2022). We also looked at the association in the opposite direction and found that female participants who reported having recurrent headaches during the previous three months achieved on average 30 minutes less MVPA per week than those who did not have headaches (Kolb et al., 2022). For recurrent back pain, it was 40 minutes less per week (Kolb et al., 2022). In the male subjects, there was no negative effect on the physical activity (Kolb et al., 2022).

However, the results only show that subjects who fulfill the WHO recommendation are less likely to report recurring headaches, or that female subjects who reported repeated headaches or back pain in the last three months achieved less MVPA. To test a causal relationship, longitudinal data is needed.

In the third article, we have chosen such a longitudinal approach. Sporting activity in a club was chosen as an indicator of physical activity. We looked at how the change in this sporting activity over time affects health. Cardiorespiratory fitness, muscular fitness, BMI, and recurrent headache were used as health indicators. We analyzed the data of 947 MoMo baseline participants (53 % female) aged 11 to 17 who also participated in the wave 1 survey about five years later. The sample was divided into two groups based on activity in the sports club. Participants with more than 240 minutes of sporting activity per week were classified as highly active and the combination of the two measurement times resulted in four groups: high active (over 240 min/week sporting activity at both times), low active (up to 240/week min sporting activity per week at both times), decreaser (over 240 min/week at the first, but not at the second time), and increaser (less than 240 min/week sporting activity at the first time, but more than 240 min/week at the second time). Overall, we came to the conclusion that the participants who were classified as highly active at both time points and those who increased their activity had better health levels at the second measurement time point (Kolb et al., 2025).

RG1: *How is physical health expressed in research on physical activity in children and adolescents?*
The first question can be answered relatively clearly with the help of the results from the review paper (Paper I). Within the research topic of the health effects of physical activity, physical health

is typically expressed through measures of body composition, cardiometabolic biomarkers, physical fitness, or bone health. The most common proxy measures reported in the reviews were BMI for body composition, blood pressure for cardiometabolic biomarkers, cardiorespiratory/aerobic fitness for physical fitness, and bone mineral content for bone health.

RG2: *What is the relationship between physical activity and physical health among children and adolescents in Germany?*

The second key question is much more complex than the first and also more difficult to answer. In the second article, we showed that participants who did not meet the WHO recommendation for physical activity had an increased risk of headache recurrence. Here, there is a positive correlation between physical activity and the positive expression of the health indicator under consideration. At the same time, the results also showed that especially girls who reported recurrent headaches (negative expression of the health variable) achieved less MVPA. The third article showed that children and adolescents who were continuously active in sports clubs had better health parameters than those children who did not participate in or reduced their activity in a sport club. It also showed that taking up a sporting activity can improve health.

All in all, it can be said that research into the relationship between physical activity and health is a major challenge. The first article of the dissertation showed that reducing health to the physical aspects leads to a simplification of the construct and thus enables the empirical examination of possible correlations in the first place. On the other hand, the article also showed that there are various indicators with which physical health can be represented and a significantly larger number of measures that reflect these indicators. The large number of indicators and variables available makes it difficult to compare results and generate evidence. A consistent approach and the use of standardized methods are essential to counteract this. Cross-sectional studies, such as the one in the second article, suggest a relationship between physical activity components and health indicators in both directions. These types of studies are helpful in revealing and classifying the relationships between physical activity or physical behavior and health. However, longitudinal data are essential to determine causal relationships between the constructs.

Figure 5.3 illustrates the complexity described by combining the representation of the facets of physical activity of Woll (2006) with the biopsychosocial model of health and disease. In addition to the complexity of the research field, the model also shows how the reduction and simplification mentioned above can be achieved on the way to an answerable research question.

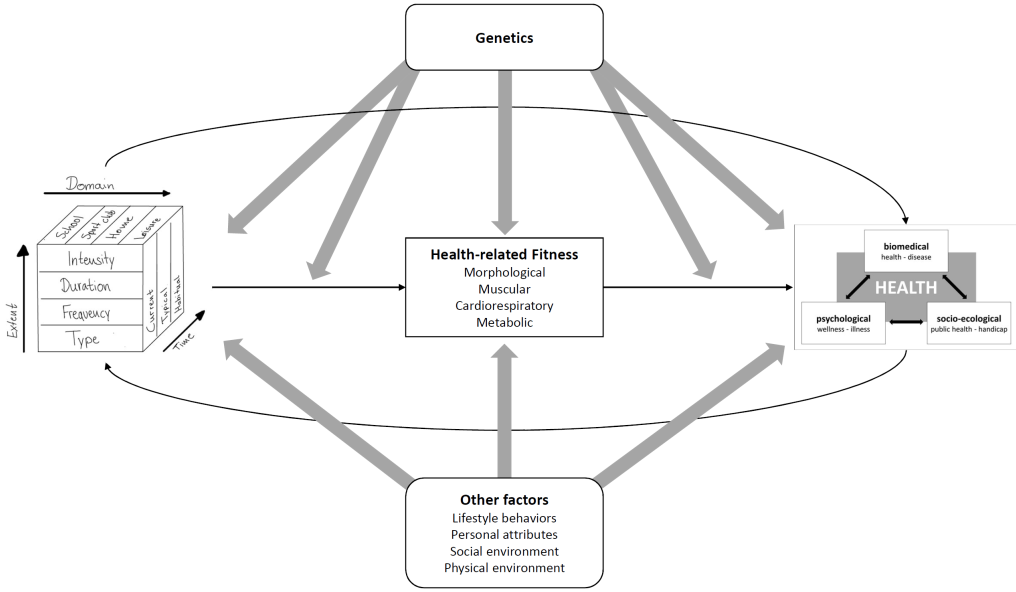


Figure 5.3: Illustration of the complexity of the relationship between physical activity and health in an extended version of the Bouchard model

5.2 The role of physical activity in reducing health risks

The health benefits of physical activity are well known and include, among other things, a lower risk of cardiovascular disease, high blood pressure, diabetes and various types of tumor. In addition, physical activity has a favorable impact on mental health, slows the onset of dementia and plays a role in maintaining a healthy weight (Guthold et al., 2018; Poitras et al., 2016; Sallis et al., 2016; World Health Organization, 2010).

While it is proposed to be a mediator between physical activity and health in the model of Bouchard (c.f. fig 2.5, Bouchard et al., 2012) physical fitness itself can be seen as an important marker of physical health (Ortega et al., 2008; Ruiz et al., 2016) which is why it is frequently used to measure health in children as our analysis in the first article had shown (Kolb et al., 2021). Better PF, and especially better CRF in childhood are associated with a better cardio profile, i. e. lower risk for CVD (Ruiz et al., 2009. Intensive training and vigorous physical activity are known to improve physical fitness (Ortega et al., 2008). Therefore, physical activity and especially vigorous physical activity reduces the risk of heart disease.

To emphasize the importance of physical activity for health, the negative consequences of physical inactivity are often presented, such as an increased likelihood of cardiovascular disease or an increased risk of premature death. In a reverse approach, Strain et al. (2020) calculated what percentage of the population was prevented from premature mortality through physical activity. They estimated the prevented fraction for the population (PFP) at 15 % (range 6.6 - 20.5) globally which conservatively equating to 3.9 million (CI95 2.5 - 5.6) premature deaths averted per year (Strain et al., 2020). This figure is based on current levels of physical activity and underlines the potential of promoting physical activity in a positive way.

5.3 Limitations and strengths of the dissertation

One strength of the work, which can also be discussed as a limitation, is the focus on physical health. From a critical point of view, it must be noted here that health is not comprehensively portrayed in this way, at least if one is guided by the biopsychosocial model on which the work is based. Mental illnesses such as depression or anxiety disorders can also occur in physically completely healthy individuals. On the other hand, the clear focus on health also brings a great advantage. In this way, it was possible to address the area of physical health in greater depth. The presentation of the health indicators used in the research, as well as the cross-sectional and longitudinal relationships between physical activity and health in all three dimensions, would have gone beyond the scope of the work.

Another point that must be mentioned is the MoMo study, which forms the data basis of the work. The strengths and weaknesses of the study are therefore also those of the present work, since it is based on the data obtained from the study. One limiting factor here is the relatively long time between the individual waves of the study, which means that other influencing factors that were not controlled for can have an effect on the target values over a long period of time. Furthermore, data collection methods were changed, added or removed from the study during the course of the study, which means that some values are only available at certain points in time or are not comparable between waves. For example, laboratory data such as blood and urine values are only available for the first wave of data collection. However, it must also be recognized that some of the changes were absolutely necessary because the study was designed over 20 years ago and since then changes have taken place in society or technology that need to be taken into account. The exceptional situation of the COVID-19-pandemic provides a vivid example, as a result of which online training and sports programs have been developed that have been very well received and that did not exist in this form and to this extent before.

One of the strengths of the MoMo study and thus of the data basis of this work is the extensive and carefully drawn sample. The register sample is considered to be the best practice method for generating a nationwide sample in Germany (Häder, 2015). The method used is described in more detail in section 3.1.2. Due to the complex procedure, it can be assumed that the sample examined represents the overall population very well, but it cannot be completely ruled out that there are groups that are not reached. . The mix of cross-sectional and longitudinal design allows the study of both social development and individual trajectories. In addition, the combination of data on physical activity, motor performance, and health is unique in this form. Last but not least, the standardized recording by trained test supervisors ensures the validity and reliability of the collected data.

5.4 Recommendations for future research

Based on the biopsychosocial model, it makes sense to focus on one of the dimensions of health and illness, as described above. In the next step, the dimensions must then be re-embedded in a common theory. In this theory, in addition to the effect of physical behavior on the individual dimensions, the interactions between these dimensions and the effect of physical behavior on these interactions must also be considered. The development of such a theory can hardly lie within the scope of a single discipline. The combination of the dimensions of illness and health alone requires expertise from medicine, biology and psychology, and the integration of physical behavior in the picture requires the sports and exercise sciences.

At the level of the relationship between physical behavior and physical health, further research is needed into which aspects of physical behavior have which effects. In doing so, the aspects should be considered in isolation and in relation to each other, as the compositional data analysis approach does. Compositional data analysis also has the advantage of taking into account the interaction between physical activity, sedentary behavior and sleep and the effect on health parameters. However, similar to the consideration of examining health in its dimensions and then integrating the results into a common theory, the individual aspects of physical behavior must also be examined in detail. Since both physical behavior and health are complex topics, clear naming and presentation, as well as transparent work and clean documentation, are indispensable for the research area. Standardization of data collection methods or guidelines for evaluation could help to compare and summarize research results from different sources.

6 Conclusion

6.1 Summary of contributions to physical activity and health research

The current dissertation examines the relationship between physical activity and health in children and adolescents in a nationwide sample from Germany. The first article of the dissertation provides an overview of the indicators and measures used to measure physical health in the population. The second and third articles examine the relationship between physical activity and health in a cross-sectional perspective (article 2) and over time (article 3). The results of the analyses in the dissertation articles underscore the health-promoting potential of physical activity. The article *Physical Activity and Recurrent Pain in Children and Adolescents in Germany—Results from the MoMo Study*. provides prevalence data for different types of pain in children in Germany and shows that children who meet the physical activity recommendation of 60 min MVPA per day have a lower chance of reporting recurring pain. At the same time, the results for girls showed an inverse effect, with participants reporting recurring headaches achieving on average more than half an hour less MVPA per week. In the third article, we were able to show that children and adolescents who participated in sports in a club to an above-average extent at two consecutive measurement points had better health values than their less active peers. However, even the uptake of sporting activity proved to be beneficial compared to a permanently below-average level of activity. In particular, the literature research conducted for the first article on the health indicators used in research also revealed gaps, such as the lack of studies on the links between physical activity and injuries and harms.

6.2 Implications for public health policy and practice

Reliable data collection is the basis for successful monitoring of health and physical activity. An important point when selecting and compiling the instruments is the collection of all relevant data while minimizing the burden on the subject. In the context of longitudinal data collection, there is also the need for comparability of the data over time.

As a full survey at national level would be extremely costly in terms of both resources and organization, the question of how to draw a suitable sample arises. Ultimately, only a register sample can be considered for comprehensive health monitoring, as this is the only way to include all age groups which is not given when using a school-based approach. The decisive question is not so much the type of sample but the desired size of the gross sample and the number of municipalities from which it is recruited. Apart from the minimum number of at least 150 municipalities, a larger number of municipalities offers various advantages. Firstly, a higher number of PSUs increases the precision of the estimates. Secondly, a sufficiently large number of units ensures that representative data is available for each federal state. This would offer a considerable benefit for health policy at state level.

Another challenge is the design of the data collection. In the first step, the constructs and variables for recording physical behavior, i.e. not only PA but also sleep and SED, physical fitness and health, must be selected. Based on the selected constructs and target values, the recording methods must be compiled. Combining different methods is recommended here, e.g. questionnaires or activity diaries to capture the type and context of PA with accelerometers to capture frequency, intensity and duration. These methods can also be used to capture SED and the contextual information. After selecting the constructs and variables and determining the data collection instruments, a research schedule must be drawn up that defines when and in which order which data is collected.

The examination schedule for a randomly selected child as part of the health monitoring program could, for example, be as follows. Once a year, an invitation is sent out to a regional examination center, where a brief medical anamnesis is carried out. Height and weight are measured and blood and urine samples are taken. Every three years, additional motor fitness tests are carried out to assess physical fitness. In addition to the visit to the examination center, the participant keeps a diary in which height and weight are recorded once a month. Additional information such as a general assessment of the current state of health would be possible. Two to three times a year, the subject is sent an accelerometer that is worn for a week and records information on PA, SED and sleep. The device-based recording of physical activity and the medical examination are supplemented by a survey of the participants, which primarily collects background information on the person's life situation. Interesting background information includes the social status of the family, access to sports clubs and activities, as well as medical care and utilization.

Due to the relevance of the topic for health policy and society as a whole, responsibility for holistic health monitoring must lie with the Ministry of Health. The implementation of the guidelines and the practical execution of the monitoring itself can be delegated to suitable bodies. However, ongoing quality assurance and permanent funding must be ensured. Federal authorities from the health sector, such as the Robert Koch Institute, or research projects from the relevant areas, which are supported by long-term funding, are the primary bodies responsible for implementation.

An important point in increasing acceptance among the population and ensuring sustainability is the processing and ongoing publication of the findings gathered. Care must be taken to ensure that the information is presented in a way that is appropriate for the target group. The focus should not be exclusively on scientific publications. Comprehensible presentations of the results for a broader public, e.g. in the form of a report, a flyer or fact sheets on which individual results are presented and explained in simple language, can help to increase visibility and make the results accessible to more people.

6.3 Closing remarks

One of the biggest problems with health promotion or preventive measures in general is that the positive effects can only be expected in the future. In the current situation, there is a certain lack of pressure to act. With regard to health, the problem is often that the pressure to do something, e.g. in the form of pain or limitations in performance, or everyday life, only becomes apparent when the child has already fallen into the well. And the effort to get the child out of the well is usually greater than preventing it from falling in. The first step in minimizing a risk is to recognize that there is a risk. Knowledge is the basis for successful action.

Even if at first glance there are more pressing problems and challenges to overcome, health, health care, and health promotion should not be neglected. What is the overcoming of personal, social or global challenges and crises worth if you lack the health to experience what you have achieved? Which brings us back to the opening quote from Schopenhauer: "Health may not be everything, but without health, everything is nothing."

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Simon Kolb obtained his Bachelor's and Master's degrees in Sports Science from the Karlsruhe Institute of Technology, where he subsequently completed his doctoral studies. During his academic training, he contributed to the MoMo project as a student assistant, initially serving as a field test manager and later assuming responsibilities for the organization and preparation of test sessions, with a particular focus on accelerometry. Following graduation, he continued his involvement in the project as a research assistant. His doctoral dissertation was based on data from the MoMo study and examined the relationship between physical activity and health outcomes among children and adolescents. On the one hand, the work addresses the question of what health can mean and how it is measured. On the other hand, correlations between health parameters and physical activity are examined in cross-sectional and longitudinal studies.

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