Physical activity and body weight among German adolescents

-

a longitudinal consideration

Dissertation accepted by
the Faculty of Humanities and Social Sciences
at the

Karlsruher Institut für Technologie

submitted for the degree of Doctor of Philosophy (Dr. phil.)
by

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Day of the oral exam: December 15th, 2015

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Danksagung

Einleitend möchte ich diese Zeilen nutzen, um mich bei den Menschen zu bedanken, die mir während der Promotionszeit mit Rat und Tat zur Seite gestanden und mich jederzeit unterstützt haben.

Mein besonderer Dank gilt…

… meinem Doktorvater, Prof. Dr. Alexander Woll, der mir die Möglichkeit zum Promovieren gab und die passenden Rahmenbedingungen bereitstellte und mir damit ein großes Maß an Vertrauen und Unterstützung entgegen brachte.

… meinem Mentor, Prof. Dr. Filip Mess, für die tolle Zusammenarbeit. Ich danke ihm für die guten und aufschlussreichen Gespräche, für die pausenlose Erreichbarkeit, für das enorme Engagement und besonders für seine durchweg positive Art. Ohne diesen Optimismus und emotionale Unterstützung wären so manche Tiefen bestimmt noch tiefer gewesen.

… meinen Kolleginnen und Kollegen, (Jun.) Prof. Dr. Anne Reimers, (Jun.) Prof. Dr. Darko Jekauc, Dr. Sarah Spengler, Dr. Nadine Mewes, Dr. Miriam Reiner, Dr. Christina Niermann, Eliane Schmocker, Steffen Schmidt, Claudia Karger, Lars Schlenker, Claudia Albrecht, Birte v. Haaren, die mein Arbeitsleben durch intensive inhaltliche und freundschaftliche Gespräche bereichern, für die emotionale Unterstützung in schwierigen Phasen und die Wertschätzung in den letzten Jahren.

… PD Dr. Annegret Mündermann und Dr. Stefanie Everke Buchanan für die Unterstützung im Publikationsprozess und die sprachliche Überarbeitung meiner englischen Artikel.

… nicht zuletzt und insbesondere meinem Mann, Patrick Henn, und meiner Familie für den uneingeschränkten Glauben an mich, die bedingungslose und permanente Unterstützung und die ermutigenden Worte.

Preface

This thesis includes the following manuscripts, published in or under review in peer-reviewed journals:

Study I:

Rauner, A., Mess F. & Woll, A. (2013). The relationship between physical activity, physical fitness and overweight in adolescents: a systematic review of studies published in or after 2000. *BMC Pediatrics, 13,* 19. doi:10.1186/1471-2431-13-19

Study II:

Rauner, A., Jekauc, D., Mess, F., Schmidt. S. & Woll, A. (2015). Tracking physical activity in different settings from late childhood to early adulthood in Germany: The MoMo Longitudinal Study. *BMC Public Health, 15,* 391. doi:10.1186/s12889-015-1731-4

In the year 2015 the author's family name changed from "Rauner" to "Henn".

Study III:

Henn, A., Mess, F., Jekauc, D. & Woll, A. (under review). Do changes in physical activity lead to changes in weight among German adolescents? Results of the MoMo Longitudinal Study. *Journal of Physical Activity and Health.*

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Abbreviations

MoMo	Motorik Modul
MoMo-PAQ	MoMo physical activity questionnaire
ICC	intraclass correlation
LTPA	leisure-time physical activity
SCPA	sports club physical activity
OPA	overall physical activity
OS index	overall sports index
SES	socioeconomic status
BMI	body mass index
SDS	standard deviation score
PWC	physical work capacity

Summary

Because of the growing degradation of health and the increase in non-communicable diseases, the present dissertation analyses the relationship between physical activity and overweight, respectively body weight, in German adolescents. Especially for the relationship between physical activity, physical fitness and health, insights already exist, but these results have not been examined systematically. In addition, there is a deficit of knowledge about the development and changes of physical activity and about the relationship between these changes in physical activity and changes in health from youth into adulthood. Therefore, the primary goal of this dissertation was to give an overview of the current state of research about the relationships between physical activity, physical fitness and overweight in adolescents and young adults (Study I). This review revealed a deficit of longitudinal studies analysing the relationship between physical activity, physical fitness and health in youth. Furthermore, physical activity should be analysed in more detail. The development of physical activity and its influence on health parameters should be considered. Studies II and III made a contribution towards closing these gaps.

Study I revealed a large number of cross-sectional studies on the relationship between physical activity, physical fitness and overweight in adolescents. In contrast, a deficit of prospective studies was found. Only two longitudinal studies analysing all three aspects were found.

In addition, the review showed little evidence of the longitudinal relationship between physical activity, physical fitness and overweight in European countries. Overall, 14 studies were found, but only six studies analysed the relationships between all three aspects. The remaining studies analysed the relationship separately for physical activity and physical fitness. Furthermore, there are only a small number of studies analysing the transition from youth into young adulthood.

Based on the model of Hallal and colleagues (2006) and because of the complexity of health parameters and determinants, the subsequent studies focussed on physical activity and body weight.

Before analysing the longitudinal relationship between physical activity and body weight, Study II considered the question of the stability of physical activity in German youth during the transition into adulthood. Overall longitudinal data of N= 947 participants (N_{boys}= 447; N_{girls}= 500) was included in the analyses. The mean ages were at t_0= 14.21 ± 2.00 and at t_1= 21.05 ± 2.05. Independently of settings of physical activity, the results of this study showed low to moderate stability ($r \leq 0.263$; $p<0.05$) in physical activity. The highest stability was shown in sports club physical activity ($r=0.248$; $p<0.001$). The Spearman correlation coefficients did not differ according to sex and social economic status. The lowest stability was shown in leisure-time physical activity outside sports clubs ($r=0.094$), followed by overall physical activity ($r=0.211$). Compared order was found for the differentiation between sex, age group and social economic status. These results showed low to moderate stability of physical activity in different settings over a six-year time span, which led to the further research project in Study III. This study analysed the question of whether changes in physical activity lead to changes in body weight. Longitudinal data of N= 913 (N_{boys}= 432; N_{girls}= 481; $mean_{aget0}$= 14.31 ± 2.00; $mean_{aget1}$= 20.52 ± 2.06) participants was considered in the analyses. Overall, a decrease in the number of minutes / days per week of physical activity in different settings was detected (overall physical activity: -0.16 ± 2.32 days; sports club physical activity: -17.92 ± 141.10 minutes; physical activity outside sports clubs: -8.76 ± 170.69). In contrast, BMI values increased between the measurement points (2.83 ± 2.71). However, stability of BMI was $r = 0.66$; $p < 0.001$. Analysed for sex, age group and social economic status, sports club physical activity showed the greatest decrease. The smallest changes were in the overall amount of physical activity (number of days with at least 60 minutes of moderate to vigorous physical activity).

The analyses of hierarchical regressions revealed no significant relationships between changes in physical activity in different settings and changes in BMI values.

These results show that physical activity is not the only significant factor in the development of overweight. They cannot confirm the direct relationship between physical activity and health in the model of Bouchard and colleagues (2007; 2012). But the results of these present studies reinforce the supposition that other lifestyle factors contribute to the maintenance of health and that further research is necessary.

Zusammenfassung

Aufgrund der zunehmenden Verschlechterung der Gesundheit und der Zunahme an Zivilisationskrankheiten hat sich die vorliegende Dissertation mit dem Zusammenhang zwischen körperlich-sportlicher Aktivität und Übergewicht, bzw. Körpergewicht, bei Jugendlichen in Deutschland auseinandergesetzt. Zwar liegen speziell zu den positiven Zusammenhängen zwischen körperlich-sportlicher Aktivität, körperliche Fitness und Gesundheit bereits einzelne Erkenntnisse vor, jedoch sind diese nicht systematisch untersucht. Zudem ist das Wissen über die Entwicklung von körperlich-sportlicher Aktivität und über den Zusammenhang zwischen dieser Entwicklung und Veränderungen von Gesundheit insbesondere im Kindes- und Jugendalter beziehungsweise im Übergang zum jungen Erwachsenenalter in Deutschland noch sehr gering. Daher war das übergeordnete Ziel der Dissertation, einen Überblick über den aktuellen Forschungsstand zum Zusammenhang zwischen körperlich-sportlicher Aktivität, körperlicher Fitness und Übergewicht bei Jugendlichen zu geben (Studie I). Dieser Review zeigt, dass insbesondere Defizite im Bereich der Längsschnittstudien zum Zusammenhang zwischen körperlich-sportlicher Aktivität, körperlicher Fitness und Gesundheit bei Jugendlichen vorliegen. Darüber hinaus sollte die körperlich-sportliche Aktivität differenzierter betrachtet und die Entwicklung und deren möglichen Einfluss auf Gesundheitsparameter analysiert werden. Mit zwei weiteren Studien zur Entwicklung der körperlich-sportlichen Aktivität bzw. deren Einfluss auf Gewichtsveränderungen wurde ein Beitrag zum Schließen dieser Defizite geleistet.

In Studie I konnte gezeigt werden, dass bereits zahlreiche Querschnittstudien zum Zusammenhang zwischen körperlich-sportlicher Aktivität, körperlicher Fitness und Übergewicht bei Jugendlichen vorliegen. Ein Mangel an

Längsschnittstudien konnte hingegen festgestellt werden. Insgesamt wurden nur zwei Längsschnittstudien gefunden, die alle drei Parameter im Jugendalter bzw. jungen Erwachsenenalter analysierten. Zudem zeigt der Review eine geringe Evidenzlage zum längsschnittlichen Zusammenhang zwischen körperlich-sportlicher Aktivität, körperlicher Fitness und Übergewicht im europäischen Raum. Von 14 gefundenen Studien analysierten nur sechs Studien den Zusammenhang zwischen allen drei Parametern. Die übrigen Arbeiten betrachteten den Zusammenhang separat für die einzelnen Parameter. Weiter existieren nur wenige Studien, die den Übergang vom Jugendalter ins junge Erwachsenenalter analysieren.

In den darauffolgenden Studien wurde in Anlehnung an das Model von Hallal und Kollegen (2006), sowie aufgrund der Komplexität, der Schwerpunkt auf die zwei Variablen „körperlich-sportliche Aktivität“ und „Körpergewicht“ gelegt.

Bevor auf den längsschnittlichen Zusammenhang zwischen Körpergewicht und Aktivität eingegangen wurde, wurde in Studie II der Frage nachgegangen, wie stabil in Deutschland die körperlich-sportliche Aktivität in den verschiedenen Settings der körperlich-sportlichen Aktivität vom Jugendalter bis ins junge Erwachsenenalter ist. In die Analyse gingen längsschnittliche Daten von insgesamt N=947 Jugendlichen ein. Diese Stichprobe unterteilte sich in N_{Jungen}=447 und $N_{Mädchen}$=500. Das mittlere Alter betrug an t_0= 14.21 ± 2.00 Jahre und an t_1= 21.05 ± 2.05 Jahre. Die Ergebnisse dieser Studie zeigten eine schwache Stabilität der körperlich-sportlichen Aktivität in den verschiedenen aktivitätsbezogenen Settings ($r \leq 0.263$, $p<0.05$). Die höchste Stabilität wies die körperlich-sportliche Aktivität im Sportverein mit $r=0.248$, $p<0.001$ auf. Die signifikanten Korrelationskoeffizienten nach Spearman unterschieden sich jedoch nicht signifikant zwischen Geschlecht und Sozialschicht. Die geringste

Stabilität zeigte die Aktivität außerhalb des Vereins (r=0.094), gefolgt von der Gesamtaktivität (r=0.211). Eine vergleichbare Reihenfolge zeigte sich für die Unterscheidung zwischen Geschlecht, Altersgruppe und Sozialschicht.

Die Ergebnisse verdeutlichten eine geringe bis mäßige Stabilität der körperlich-sportliche Aktivität in den verschiedenen Settings über eine Zeitspanne von 6 Jahren. Daraus ergab sich das weitere Forschungsvorhaben für Studie III. Darin wurde der Frage nachgegangen, ob eine Veränderung im Aktivitätsverhalten auch zu einer Veränderung im Körpergewicht führt. In die Berechnungen gingen längsschnittliche Daten von insgesamt N=913 Jugendlichen und jungen Erwachsenen ein (N_{Jungen}=432; $N_{Mädchen}$=481). Das durchschnittliche Alter lag zum ersten Messzeitpunkt bei 14.31 ± 2.00 Jahren, zum zweiten Messzeitpunkt bei 20.52 ± 2.06 Jahren.

Insgesamt war für alle Settings der körperlich-sportlichen Aktivität (Gesamtaktivität: -0.16 ± 2.32 Tagen; Aktivität im Verein: -17.92 ± 141.10 Minuten; Aktivität außerhalb des Vereins: -8.76 ± 170.69 Minuten) ein signifikanter Rückgang der Minuten / Tage pro Woche zu verzeichnen, während die BMI-Werte zwischen den beiden Messzeitpunkten im Mittel um 2.83 ± 2.71 Punkten zunahmen. Die Stabilität des BMI lag dennoch bei r=0.66, p<0.001.Im Mittel wies die Vereinsaktivität, analysiert für Geschlecht, Altersgruppe und Sozialschicht, den höchsten Rückgang über eine Zeitspanne von 6 Jahren auf. Die geringste Veränderung zeigte die Anzahl der Tage, an denen die Probanden für mindestens 60 Minuten am Tag moderat bis intensiv körperlich-sportlich aktiv sind.

Die Berechnungen der hierarchischen Regressionen ergaben keine signifikanten Zusammenhänge zwischen den Veränderungen der Aktivität in den verschiedenen Settings der körperlich-sportlichen Aktivität und der Veränderung der BMI-Werte.

Diese Ergebnisse können den direkten Zusammenhang zwischen körperlich-sportlicher Aktivität und Gesundheit im Modell von Bouchard und Kollegen (2006; 2012) nicht bestätigen. Dennoch unterstreichen sie die Annahme, dass neben der körperlich-sportlichen Aktivität weitere Faktoren in der Entstehung von Übergewicht bzw. Aufrechterhaltung von Gesundheit bedeutsam sind und daher weiterführende wissenschaftliche Analysen, besonders in der Lebensstilforschung, durchgeführt werden müssen.

1 General introduction

In recent years, an increasing decline in health has been observable. Especially in developed countries, there has been an increase in non-communicable diseases (World Health Organisation, 2015b). The causes are multifactorial and are frequently connected with lifestyle changes. Time spent on physical activity has decreased, whereas inactivity is becoming more and more prevalent (World Health Organisation, 2015d). To date, more than 80% of adolescents worldwide do not meet the physical activity recommendation of at least 60 minutes of moderate to vigorous physical activity per day (World Health Organisation, 2015e). Furthermore, adolescents spend a great deal of time using electronic media and do not consume the recommended daily allowance of fruit and vegetables (Barr-Anderson & Sisson, 2012; Mensink, Kleiser, & Richter, 2007). These lifestyle factors can lead to diseases of civilisation.

1.1 Physical activity and health from adolescents to young adulthood

As well as cancer, cardiovascular diseases, chronic respiratory diseases, diabetes and mental health problems and obesity are also frequently occurring non-communicable diseases (World Health Organisation, 2015b). Overweight and obesity are especially dangerous because of their high stability over time (Herman, Craig, Gauvin, & Katzmarzyk, 2009; OECD, 2014). Thus, overweight or obese youths often also suffer from overweight or obesity in adulthood. This can lead to multiple health consequences in youth, but even more so in adulthood. Overweight and obesity promote the development of vascular diseases and increase the risk of diabetes mellitus type 2 and hypertension (Verband für Ernährung und Diätetik e.V., 2014), which can lead to an increased risk of morbidity and mortality (World Health Organisation, 2015b). In

2010, overweight and obesity were the estimated causes of 3.4 million deaths and of 3.9% of years of life lost worldwide (Ng et al., 2014). According to the Global Burden of Disease Study 2013 (Ng et al., 2014), their prevalence has increased substantially from 1980 to 2013 in children and adolescents in developed countries (23.8% of boys and 22.6% of girls) as well as in developing countries (from 8.1% to 12.9% in 2013 for boys and from 8.4% to 13.4% for girls). This data emphasizes the need for programs and interventions based on empirical findings about the relationships between the different key lifestyle aspects. The challenge is now to identify the different factors of the complex construct “health”. One of these factors is physical activity. Because of the numerous health benefits, physical activity, as a determinant of health, is an important aspect in the prevention and treatment of health restrictions. In addition to the need for programs and interventions, the numbers presented showed that a special focus should lie on youth because health problems begin and some behaviour patterns manifest as early as in childhood and adolescence (Spengler, 2014).

At a theoretical level, Hallal and colleagues (Hallal, Victora, Azevedo, & Wells, 2006) illustrated the health benefits of physical activity during adolescence in Figure 1. Based on an extensive literature search, four pathways were identified:

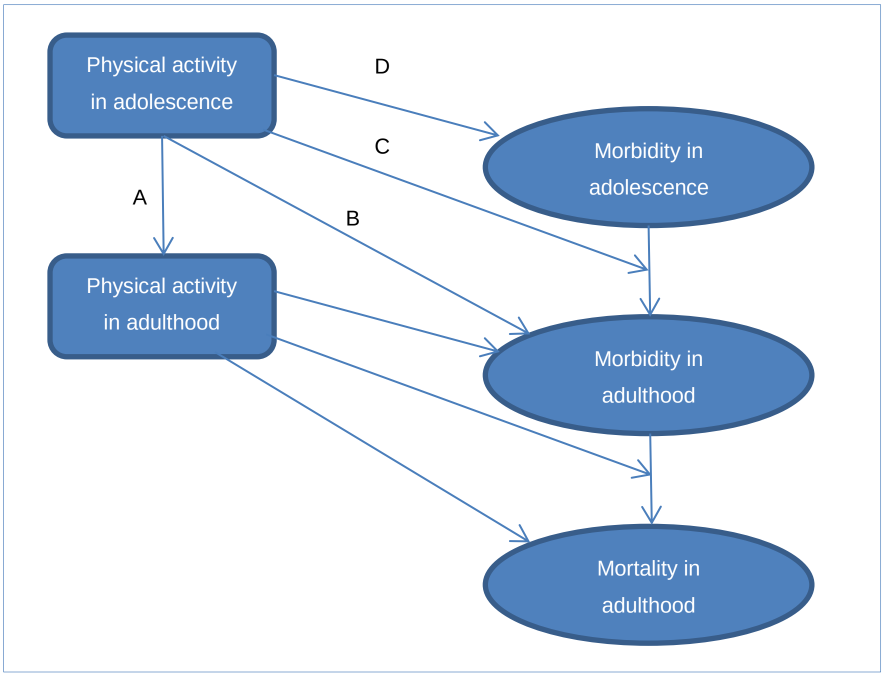


Figure 1 - The association between adolescent physical activity and health (adapted from Hallal et al. (2006))

Pathway A: Physical activity during adolescence influences physical activity in adulthood and thereby health and wellbeing.

Pathway B: Physical activity during adolescence directly influences morbidity in adulthood.

Pathway C: Physical activity during adolescence influences the treatment and prognosis of adolescent morbidity.

Pathway D: Physical activity during adolescence influences adolescent morbidity.

In recent years, knowledges in health research, especially on the health benefits of physical activity, have increased steadily. As well as numerous (cross-sectional) studies on children (e.g. Telama, 2005; Aires, 2010; Basterfield, 2011) there are also some studies on adolescents and adults (e.g. Anderssen, 2005; Azevedo, 2007; Craigie, 2011; Eisenmann, 2004; Hallal, 2012) analysing these different pathways. However, there is a deficit of longitudinal studies, especially representative studies or at least studies with a large study population. Additionally, the evidence in European and national studies is small.

1.2 Aims and outline of the dissertation

To develop promising health promotion programs and interventions, empirical findings on the relationships between physical activity and health are necessary. But because of the existing deficit of longitudinal health studies, more research in this field is necessary. Thus, the overall goal of the present thesis is to provide input and to contribute to European and longitudinal research on adolescent physical activity and its relationship with health, especially with body weight. Only with sufficient empirical findings and extensive evidence will it be possible to create promising health promotion programs and interventions.

For achieve this goal, several steps were necessary. Referring to Reimers (2013), five steps were identified and are presented in Figure 2.

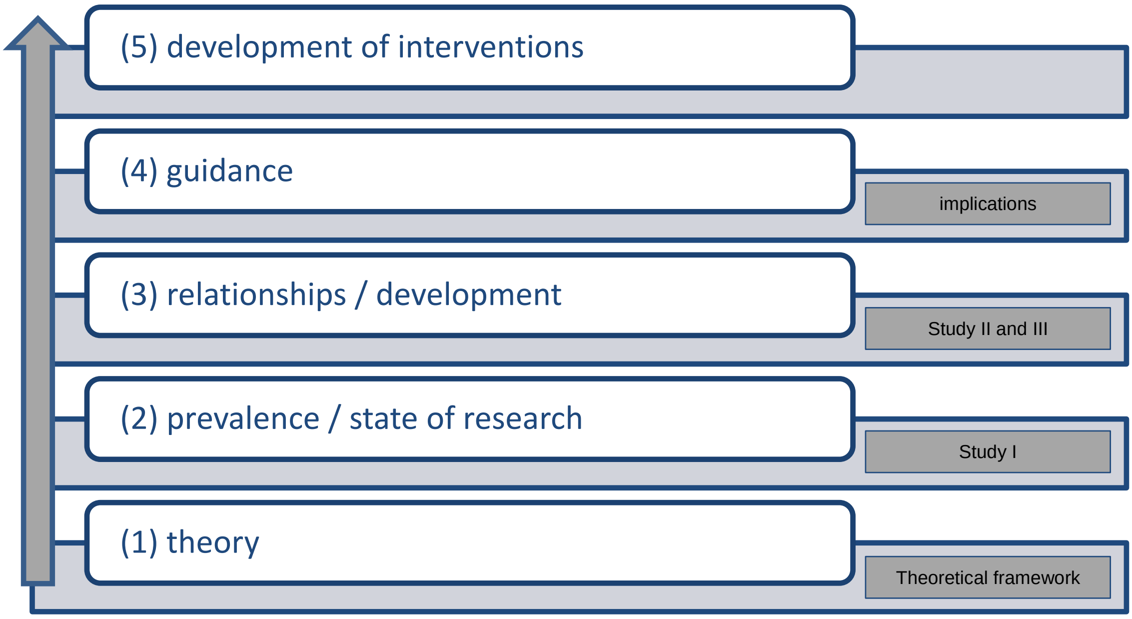


Figure 2 - Overview of the necessary steps for research in health promotion (referring to Reimers (2013))

Each research project should be based on a theory (Step 1). In Chapter 2, the theoretical framework for the relationship between adolescent physical activity and health outcomes (in the present thesis especially overweight) is presented.

The next step (Step 2) contains a description of the necessity to adopt measures as well as a comprehensive analysis of literature. This step gives an overview of the current state of research and consequential research gaps (Chapter 3).

The main goal of **Study I** was to give an overview of the state of research into physical activity, physical fitness and overweight among adolescents. This review summarized the existing cross-sectional and longitudinal studies in or after 2000. In addition to physical activity, physical fitness (motor skills as well as cardio-respiratory fitness) was also considered. The overall result of this study was that there is a deficit of national and international longitudinal studies, especially representative studies. Also, there were no studies analysing physical activity separately in different settings of physical activity. Longitudinal studies are necessary to develop implications for interventions.

The aim of the following step (Step 3) is to analyse the different relationships between physical activity and weight. Because of the longitudinal consideration and the question of how physical activity changes over time, firstly the development of physical activity was analysed (**Study II**, Chapter 4). The aim of this study was to analyse the dstability of physical activity in Germany from adolescence into young adulthood. That implies the question of how the stability of physical activity influences weight changes over the time period from adolescence into young adulthood. The specific aim of **Study III** (Chapter 6) was to assess the relationship between changes in physical activity and changes in weight among German adolescents.

The next steps (Steps 4 and 5) are the development of guidance (Chapter 6.3) and interventions. Based on the results of the analyses, different recommendations for the treatment and prevention of health problems can be developed. The selection of further research implications is another aim of these steps.

Before the description of the implications, a summary and an overall discussion of the main results of Studies I to III will be presented in Chapter 6.

2 Theoretical framework

In this chapter, the definitions of essential terms and the theoretical foundation are presented.

2.1 Definitions

Physical activity is defined by Caspersen, Powell, and Christenson (1985) as “any bodily movement produced by contraction of skeletal muscle that substantially increases energy expenditure”. This definition covers all bodily movements of a person in different settings (e.g. housework, at work, leisure-time activities, hard training, physical education) (Caspersen et al., 1985). Not included are internal physical movements like peristalsis and intellectual activities like chess (Wagner, Woll, Singer, & Bös, 2006). This clarifies that physical activity consists of purely voluntary movement (e.g. competitive sports), inevitable movement (e.g. work, housework) or conscious movement (maintenance of health) (Shephard & Miller, 1998). Physical activity can be measured by different parameters – intensity, duration and frequency. These three aspects are important for the impact of physical activity on health. When focussing on the effect on health outcomes, the duration and frequency of at least moderate physical activity is decisive.

Physical fitness is “a set of attributes that are either health- or skill-related” (Caspersen et al., 1985). The skill-related components include agility, balance, coordination, speed, power and reaction time. The health-related components consist of cardio-respiratory endurance, muscle strength and endurance, body composition and flexibility. The five health-related components of physical fitness are of greater importance to public health (Caspersen et al., 1985).

Health is defined as “a state of complete physical, social and mental well-being, and not merely the absence of disease or infirmity. Health is a resource for everyday life, not the object of living, and is a positive concept emphasizing social and personal resources as well as physical capabilities” (World Health Organisation, 2015a). Health is influenced by different health determinants. These determinants are forces or elements that affect health, either positively or negatively (World Health Organisation, 2015a).

Health can be measured by different outcome variables. These include psychological variables (mental health) as well as aspects like hypertension or overweight. Consideration of body weight as an outcome variable of health is difficult because body weight in itself does not determine health.
But one way of considering body weight as a health outcome variable is the fact that normal weight is associated with good health whereas overweight is associated with poor health and/or illness. Normal BMI values are considered to be “healthy”, whereas high BMI values are seen as “unhealthy”. Another approach, following Caspersen et al. (1985) is the fact that body composition, measured via Body Mass Index, constitutes one aspect of health-related fitness. But in view of the common perception of body weight as a parameter of health, body weight can be regarded as a health outcome variable.
In a further step body weight is often operationalized by calculating the body mass index (BMI). Because BMI has a high correlation with body fat (Centers for Disease Control and Prevention, 2015; Ranasinghe et al., 2013), health outcome variables, especially overweight and obesity, can be measured with the aid of this method in adults as well as in adolescents (whereby here specific percentiles based on BMI values that take age and sex into consideration are

observed). Overweight / obesity is one of the different outcome variables of health and is defined as abnormal or excessive fat accumulation that may impair health (World Health Organisation, 2015a). Although a high body fat content can lead to several non-communicable diseases (e.g. cardiovascular diseases, diabetes, musculoskeletal disorders) and can therefore cause some medical problems, the definition of obesity as a disease is internationally controversial. In Germany, however, adiposity has been accepted as an illness since 2014 according to the guidelines of the "Deutschen Adipositas Gesellschaft" (Deutsche Adipositas-Gesellschaft & Deutsche Gesellschaft für Ernährung, 2014). Based on the previous explanation, body weight, operationalised by BMI, is considered as an outcome variable of health in the present thesis.

2.2 The interaction between physical activity, health-related fitness and health

In different steps, Bouchard, Blair, and Haskell (2012) developed a model describing the relationships between physical activity, health-related fitness and health status.

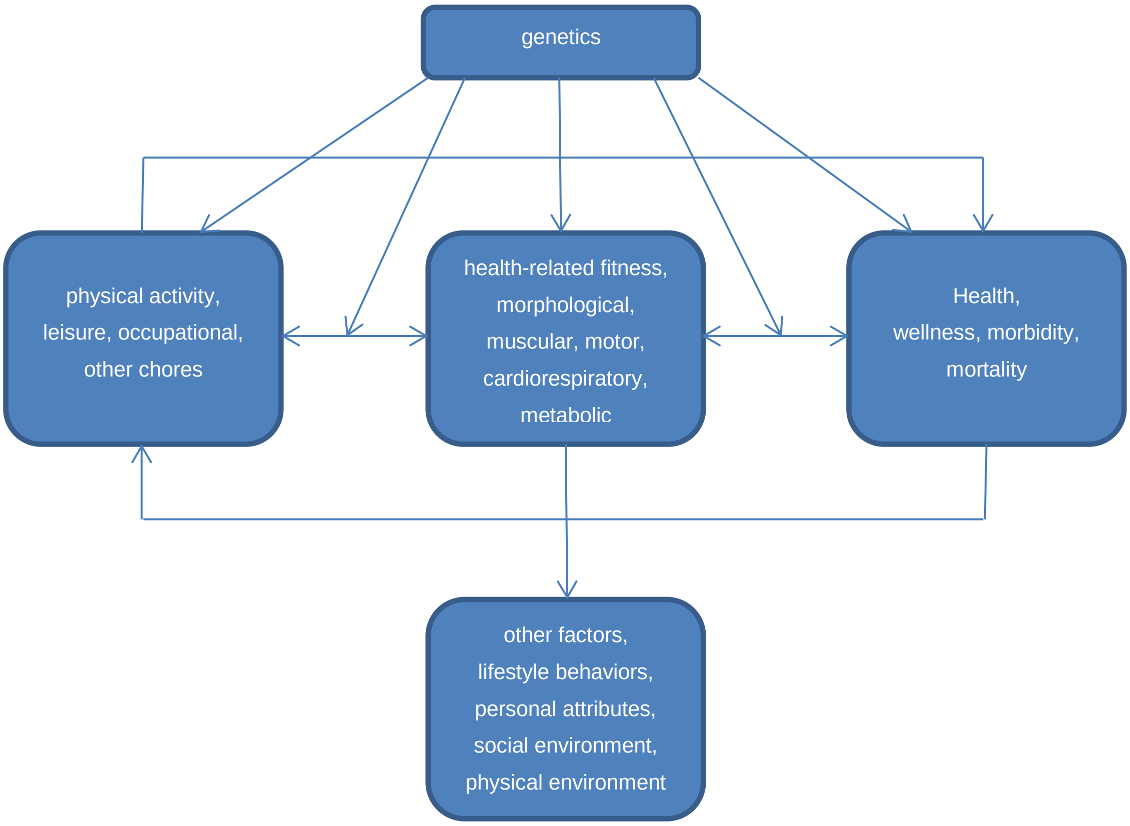


Figure 3 - Interaction between physical activity, health-related fitness and health (Bouchard, Blair, & Haskell, 2007; Bouchard et al., 2012)

Figure 3 shows that "physical activity can influence fitness, which in turn may modify the level of habitual physical activity" (Bouchard et al., 2012). Bouchard et al. (2012) clarify that people do not exclusively tend to become more active with increasing fitness and that the fittest do not tend to be the most active. The model indicates that fitness is related to health in a reciprocal manner. That means that fitness influences health and health also influences both fitness levels and physical activity levels. These relationships are also influenced by other factors, so that the level of fitness is not entirely determined by the individual level of physical activity (Bouchard et al., 2012).

For the present thesis, the direct relationship between physical activity and health is of importance. The model also shows that physical activity can directly influence various health outcomes and vice versa. Based on the assumptions in this model, the relationship between physical activity and overweight (or rather weight as a health outcome) was analysed. Because the model developed by Bouchard and colleagues (Bouchard et al., 2012) refers mainly to cross-sectional studies, the middle part of model was modified and combined with the model of Hallal and colleagues (presented in Chapter 1).

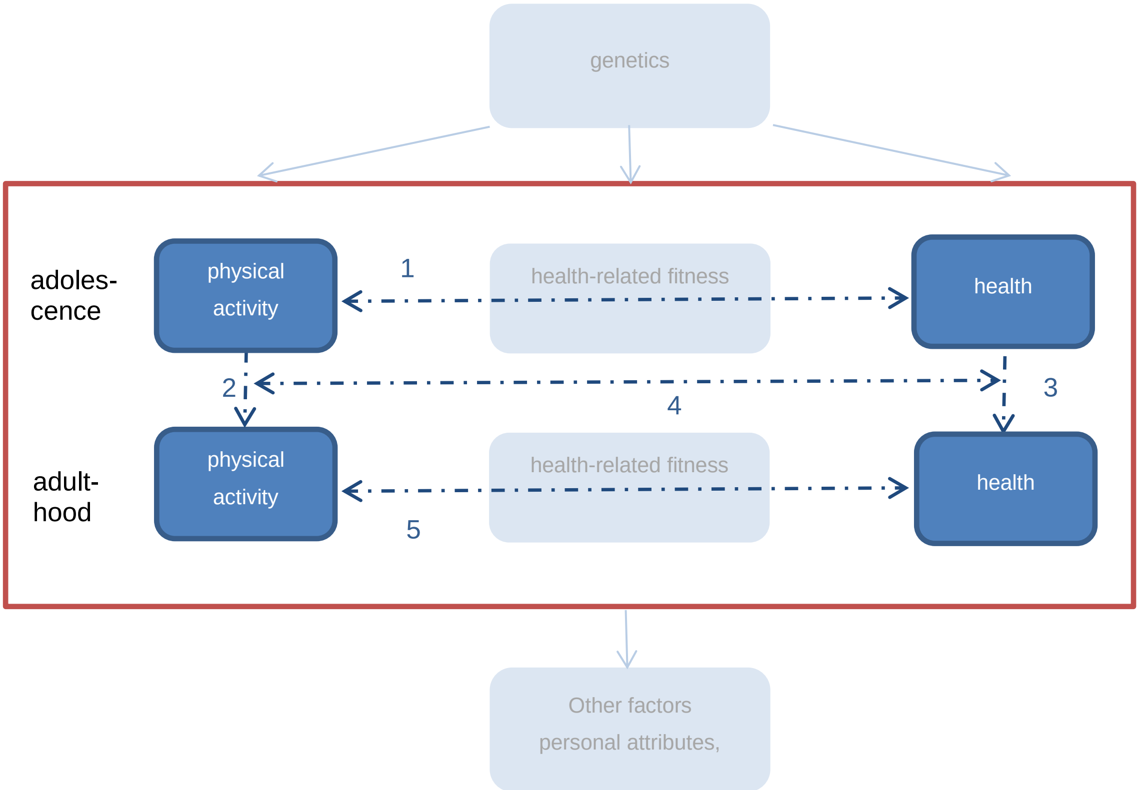


Figure 4 – Model analysing the cross-sectional and longitudinal relationship between physical activity and health
(Bouchard et al. (2007) modified and added by Hallal et al. (2006))

This model describes the cross-sectional and longitudinal relationship between physical activity and different health outcomes. Pathway 1 illustrates the cross-sectional relationship between physical activity and health. Pathways 2 and 3 describe the stability of physical activity, respectively health outcome variables, from adolescence to adulthood. Pathway 4 considers the longitudinal relationship between changes in physical activity and changes in health status.
Pathway 5 illustrates the cross-sectional relationship between physical activity and health in adulthood.

Based on this model, the present research project was developed.
In Chapters 3 to 5 of this thesis, the studies that have already been carried out are presented:
Study I gives an overview of the state of research on physical activity, physical fitness and overweight (Pathway 1).
Because of the complexity of the model, the focus in Studies II and III was initially on physical activity:
Study II describes the longitudinal development of physical activity from youth to adulthood (Pathway 2).
Study III analyses the relationship between changes in physical activity and changes in body weight (Pathway 4).

3 Overview of the state of research

Study I: The relationship between physical activity, physical fitness and overweight in adolescents: a systematic review of studies published in or after 2000.

Background

Overweight and obesity has been called a global epidemic by the World Health Organization (World Health Organisation, 2000). The prevalence of overweight and obesity is especially dramatic in economically developed countries (Wang & Lobstein, 2006) and not only in adults but also in children and adolescents. In Germany for instance, 17% of adolescents aged 14 to 17 years are overweight and nearly 9% are obese (Kurth & Schaffrath Rosario, 2007). Similarly, in the United States, 18% of adolescents aged 12 to 19 years were obese in 2007/2008 (Ogden & Carroll, 2010). In accordance with the literature (Aires et al., 2010; Fogelholm, Stigman, Huisman, & Metsamuuronen, 2008; Haerens, Deforche, Maes, Cardon, & De Bourdeaudhuij, 2007; He et al., 2011; Ortega, 2010), the term overweight includes obesity in this review.

Several health conditions and disorders have been attributed to being overweight in children and adolescents (Daniels, 2006). For instance, overweight children and adolescents are more likely to suffer from cardiovascular, metabolic, pulmonary, skeletal or psychosocial disorders (World Health Organisation, 2012). Even if these conditions or disorders are not manifested during childhood, being overweight in childhood increases the risk of illness in adulthood (Daniels, 2006). Hence, it is critical to identify risk factors for overweight in children and adolescents and to address overweight during childhood and adolescence.

Being overweight may originate from many different factors ranging from environmental influences to genetic variations (Hebebrand, Wermter, & Hinney, 2004). The heritability of predisposition for a high body mass index (BMI) or body fat content is between 25 and 40% (Bouchard, Malina, & Pérusse, 1997), which suggests that other factors such as environmental factors may also play a critical role. According to Bouchard et al. (Bouchard et al., 1997), both the family environment and genetic predisposition influence the development of body fat content and distribution. Other important factors include lifestyle factors such as physical activity (PA), nonsmoking, high-quality diet, sedentary activities and normal weight (Pronk et al., 2004). Lifestyle factors are also important in the description of the obesogenic environment that is based on the four pillars family, sport and leisure time, eating behavior and social education (Wabitsch, 2004).

Several epidemiological and intervention studies (DiPietro, 1995; Wareham, van Sluijs, & Ekelund, 2005) have identified the role of physical activity and physical fitness for overweight in children and adolescents, and hence we focused on the role of sport during leisure time. Previous reviews (Jimenez-Pavon, Kelly, & Reilly, 2010; Must & Tybor, 2005; Oja et al., 2011) provided an overview of studies on the relationship either between physical activity and overweight or between fitness and overweight in children or adolescents. Despite of the influence of physical activity and fitness similarly on health outcomes including overweight, to date results of studies on the interaction between all three parameters have not been synthesized although these parameters cannot be considered independently (Brandes, 2012). In addition, most reviews omitted studies on adolescents and young adults or did not include longitudinal studies.

The purpose of this systematic review was to provide an overview of cross-sectional and longitudinal studies published in or after 2000 on physical activity, fitness, and overweight in adolescents, and to identify mediator and moderator effects in the interrelationship among these three parameters particularly considering gender differences because of the significant differences in these parameters between boys and girls (Trost et al., 2002).

Definitions

Physical activity comprises all modes of movement caused by muscle activity resulting in increased energy expenditure (Must & Tybor, 2005; Ortega, Ruiz, Castillo, & Sjostrom, 2008).

Physical fitness consists of the three components muscle strength, endurance and motor ability, and is a prerequisite for completing daily activities without fatigue and for participating in leisure time activities (Malina & Katzmarzyk, 2006).

Overweight and obesity are defined as abnormally high fat content that may impair health and as high bodyweight (exceeding the standard measure) caused by an increased fat consumption (World Health Organisation, 2012).

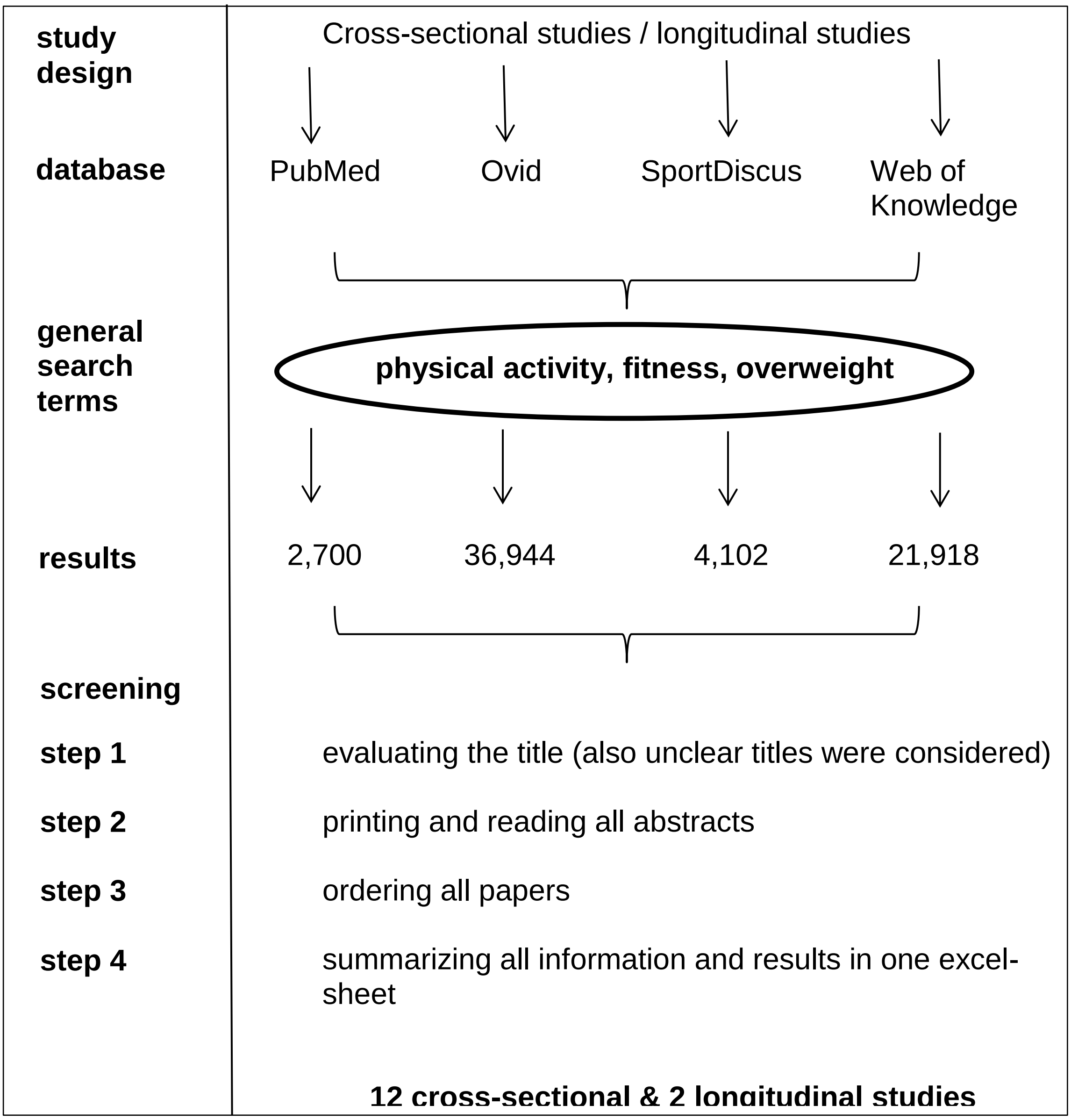
Methods

Data Collection

One author (AR) searched the electronic academic databases *PubMed*, *SportDiscus*, *web of knowledge* and *Ovid* for relevant studies. The following search terms were used: [“physical activity” or “fitness” or “exercise”] and [“obes*” or “overweight” or “weight gain” or “BMI”] and [“youth” or “adolescents”]. The data collection was completed in October 2011 (date of last search: 28/10/2011).

The four-step search strategy is illustrated in figure 5. In step 1, articles were screened based on title; in step 2, articles were selected based on the abstracts; in step 3 full versions of included articles were ordered; and all information was summarized in step 4. The abstracts formed an important element of the selection process and were used as decisive criterion for ordering full versions of the articles.

Figure 5 - Four-step search strategy



Inclusion criteria

We included only cross-sectional studies with study populations (prospective cohort studies with random sample) aged 11 to 19 years and longitudinal studies with an upper age limit of 23 years. However, two cross-sectional studies with a target group aged 7 to 12 years were also included because the age range of the study population overlapped with the target age range and the results were comparable with findings of other included studies. The search was limited to articles published in or after 2000 with physical activity and physical fitness as exercise components because research on childhood and adolescence overweight and its interaction with physical activity and physical fitness has greatly increased since 2000. Only articles published in English were included.

Exclusion criteria

Intervention studies, clinical trials, overviews and summarizing reviews and studies that did not analyse all three parameters physical activity, physical fitness (motor or cardiorespiratory fitness) and overweight were excluded.

Results

The literature search of the four databases yielded 65,664 hits (figure 5). Twelve cross-sectional and two longitudinal studies fulfilled all criteria and were included after the screening process.

Measurements

Assessment of overweight

All included cross-sectional studies used BMI as measurement of overweight or obesity (Aires et al., 2010; Ara, Moreno, Leiva, Gutin, & Casajus, 2007; Deforche et al., 2003; Fogelholm et al., 2008; Gonzalez-Suarez & Grimmer-Somers, 2011; Haerens et al., 2007; Huotari, Nupponen, Laakso, & Kujala, 2010; Lohman et al., 2008; Ng, & Willows, 2006; Ortega, 2010; Ortega et al., 2007; Pate, Wang, Dowda, Farrell, & O'Neill, 2006). Height and weight were quantified in ten studies (Aires et al., 2010; Ara et al., 2007; Deforche et al., 2003; Gonzalez-Suarez & Grimmer-Somers, 2011; Haerens et al., 2007; Huotari et al., 2010; Lohman et al., 2008; Ng et al., 2006; Ortega et al., 2007; Pate et al., 2006) and self-reported in two studies (Fogelholm et al., 2008; Ortega, 2010). In both longitudinal studies, BMI was used to determine overweight or obesity (Aires et al., 2010; He et al., 2011). In two studies, waist circumference was also determined (Ng et al., 2006; Ortega et al., 2007), and in five studies (Ara et al., 2007; Deforche et al., 2003; Lohman et al., 2008; Ng et al., 2006; Ogden & Carroll, 2010) skinfold thickness was measured. Only one study used bioelectrical impedance analysis (BIA) (Haerens et al., 2007) and one study used Dual Energy X-ray Absorptiometry (DXA) (Lohman et al., 2008) for determining overweight or obesity.

Measurement of physical fitness

Four cross-sectional studies included both cardiorespiratory and motor fitness (Ara et al., 2007; Deforche et al., 2003; Fogelholm et al., 2008; Gonzalez-Suarez & Grimmer-Somers, 2011). The other eight cross-sectional studies (Aires et al., 2010; Haerens et al., 2007; Huotari et al., 2010; Lohman et al., 2008; Ng et al., 2006; Ortega, 2010; Ortega et al., 2007; Pate et al., 2006) and the two longitudinal studies (Aires et al., 2010; He et al., 2011) assessed only cardiorespiratory fitness.

Measurement of physical activity

The included studies measured physical activity using several different methods. Five studies used objective measurements such as accelerometry (Aires et al., 2010; Haerens et al., 2007; Lohman et al., 2008; Ortega, 2010) and pedometry (Ng et al., 2006). Ten studies (eight cross-sectional and two longitudinal studies) used subjective measurements derived from questionnaires with items relating to the setting (at school, outside school; divided into leisure time physical activities at sport clubs and leisure time physical activities outside of sports clubs) and intensity of physical activities (Ara et al., 2007; Deforche et al., 2003; Fogelholm et al., 2008; Gonzalez-Suarez & Grimmer-Somers, 2011; Haerens et al., 2007; Huotari et al., 2010; Ortega et al., 2007; Pate et al., 2006). Only one study collected both objective and subjective data on physical activity (Haerens et al., 2007). Most studies analysed the relationship between overweight, physical activity and physical fitness using analyses of variance (ANOVA) and (linear and logistic) regression analysis.

Associations between physical activity, physical fitness and overweight in cross-sectional studies

Twelve studies met the inclusion criteria of this review. While all twelve studies assessed physical activity, physical fitness and overweight, only four studies analysed the interaction among these three parameters. Because some studies did not report actual data but only an interpretation of their findings, statistical parameters could only be included for some studies. The results of all included studies are summarized in Table 1. For completeness, we also report the results of those studies that assessed all three parameters but not their interaction. Throughout this article, we distinguish between genders because of the significant differences in physical activity, physical fitness and overweight between boys and girls (Trost et al., 2002).

Table 1 - Cross-sectional and longitudinal studies examining the relation between physical activity, physical fitness and overweight in adolescents

Reference	**Study design**	**Anthropo-metrics**	**Cardio-respiratory fitness**	**Motor fitness**	**Objective physical activity**	**Subjective physical activity**	**Results**
Deforche et al. (2003)	cross-sectional; age: 12–18 years, N=3,214	BMI (Cole, Bellizzi, Flegal, & Dietz, 2000), 5 skinfold thickness	shuttle run	10x5m shuttle run, standing broad jump, sit and reach, flamingo balance, plate tapping, sit ups, bent arm hang	-	sport index and leisure-time index	Fitness: speed shuttle run: sign. association with obesity (F= 134.4; p<0.001). endurance shuttle run: sign. association with obesity (F= 359.3; p<0.001). handgrip: sign. association with obesity (F= 40.9; p<0.001). plate tapping and sit and reach: similar for both groups. PA: no differences in leisure-time index.
Ng et al. (2006)	cross-sectional; age: 9–12 years, N=82	BMI (Cole et al., 2000), WC, 5 skinfold thickness	shuttle run	-	pedometers (2 days)	-	Fitness: sign. lower fitness scores in obese children (F= 21.0; p<0.001). PA: not sign. among body mass groups.
Pate et al. (2006)	cross-sectional; age: 12 to 19 years; N= 3,287	BMI (Kuczmarski et al., 2000)	submaximal treadmill exercise test	-	-	MET sedentary activities	Fitness: sign. higher CRF levels in normal weight than in overweight youth (p<0.001). PA: no analyses.

Sign. = significant; PA = physical activity; CRF = cardiorespiratory fitness; BMI = body mass index; MPA = moderate physical activity; MVPA = moderate-to-vigorous physical activity; VPA = vigorous physical activity; VVPA = very vigorous physical activity, WC = waist circumference; WHR = waist to hip ratio; LTPA = leisure-time physical activity; SSF = skinfold thickness; STF = truncal subcutaneous fat; PWC = physical work capacity

Table 1 - continued

Reference	Study design	Anthropo-metrics	Cardio-respiratory fitness	Motor fitness	Objective physical activity	Subjective physical activity	Results
Ara et al. (2007)	cross-sectional; age: 7–12 years; N=1,068	BMI (Cole et al., 2000), 6 skinfold thickness	shuttle run	10x5m shuttle run, flexibility, standing long jump, sit ups, handgrip, bent arm hang	-	categorized into active/not active	<u>Fitness:</u> low correlations between fat mass and fitness parameters (r< 0.32), (except for CRF: r between 0.48 and 0.51; p<0.01 and bent arm hang: r between 0.36 and 0.40; p<0.01). CRF: strongest correlation with BMI and fat mass compared to PA) <u>PA:</u> trend to lower values in skinfold thicknesses in the active group (p= 0.07).
Haerens et al. (2007)	cross-sectional; age: 11–13 years; N=222	BMI (Cole et al., 2000), BIA	Cooper test	-	accelero-meter	active transportation index, sports index, physical activity at school index, leisure-time physical activity index	<u>Fitness:</u> main effect of weight status (F= 36.63, p<0.001) in the CRF. Sign. differences in the running capacity test (F= 46.17; p<0.001). <u>PA:</u> sign. differences in leisure time (F= 4.48; p<0.05); no sign. differences in total PA levels, school PA, active transportation and sport. Sign. association between overweight and MPA (F= 6.13; p= ≤ 0.05). Sign. association between overweight and MVPA (F= 6.55; p≤0.05). No sign. associations between overweight and total PA, active transportation, sport, school PA und LTPA.

Sign. = significant; PA = physical activity; CRF = cardiorespiratory fitness; BMI = body mass index; MPA = moderate physical activity; MVPA = moderate-to-vigorous physical activity; VPA = vigorous physical activity; VVPA = very vigorous physical activity, WC = waist circumference; WHR = waist to hip ratio; LTPA = leisure-time physical activity; SSF = skinfold thickness; STF = truncal subcutaneous fat; PWC = physical work capacity

Table 1 - continued

Reference	Study design	Anthropo-metrics	Cardio-respiratory fitness	Motor fitness	Objective physical activity	Subjective physical activity	Results
Ortega et al. (2007)	cross-sectional; age: 13–18.5 years; N=2,859	BMI (Cole et al., 2000); WC	shuttle run	-	-	leisure-time PA index, active commuting to school, MET sedentary activities	Fitness: inverse correlation between BMI-adjusted WC and CRF ($p \leq 0.05$). PA: no sign. associations between BMI($p>0.05$) or WC ($p>0.05$) and LTPA. Fitness & PA: inverse correlation between WC / BMI and CRF, independent of sedentary activities or PA (data not shown). Association between lower obesity risk (when measured by WC) and fitness / sedentary activities, not in PA.
Fogelholm et al. (2008)	cross-sectional; age: 15–16 years; N=2,266	BMI (Cole et al., 2000)	shuttle run	sit ups, sit and reach, back and forth jumping, five jump, ball skill test, coordination test	-	frequency of PA	Fitness: significant effect of overweight for all tests, excluding sit and reach ($p<0.002$). Sign. association between five-jump, endurance shuttle run and fitness index and overweight (ß-coefficients: -0.02 to -0.26; $p<0.001$; R^2: 0.14 to 0.32). PA: no differences between PA level and weight groups Fitness +PA: poorer results in all fitness tests for overweight regardless of PA levels. PA explained more variance in fitness test results than BMI.

Sign. = significant; PA = physical activity; CRF = cardiorespiratory fitness; BMI = body mass index; MPA = moderate physical activity; MVPA = moderate-to-vigorous physical activity; VPA = vigorous physical activity; VVPA = very vigorous physical activity, WC = waist circumference; WHR = waist to hip ratio; LTPA = leisure-time physical activity; SSF = skinfold thickness; STF = truncal subcutaneous fat; PWC = physical work capacity

Table 1 - continued

Reference	Study design	Anthropo-metrics	Cardio-respiratory fitness	Motor fitness	Objective physical activity	Subjective physical activity	Results
Lohman et al. (2008)	cross-sectional; age: 14 years; N=1,440	high and weight, 1 skinfold thickness, percent fat (DXA, BMI, skinfold thickness)	PWC 170	-	actiGraph	-	<u>Fitness:</u> correlation with PWC 170: fat free mass (r= 0.26 p<0.05) fat mass (r= 0.16, p<0.5), body composition (r= -0.36 to -0.54). <u>PA:</u> Inverse correlation between MVPA and BMI and MVPA and fat mass (r= -0.14 and r=-0.12, p<0.05). <u>Fitness + PA:</u> high level of PA, average %body fat: high fitness level. Low level of PA, average %body fat: low fitness level.
Aires et al. (2010)	cross-sectional; age: 11–18 years; N=111	BMI (Cole et al., 2000)	shuttle run	-	accelero-meter	-	<u>Fitness:</u> overweight youth: sign. lower CRF levels (p<0.05); BMI inverse correlation with CRF (r=-0.2, p<0.05); CRF pos. correlated with VPA (r=0.39, p<0.001), VVPA (r= 0.28, p<0.001), the amount of PA (r= 0.28, p<0.001). Higher levels of CRF: lower relative risk of being overweight/obese (OR=0.968 (0.939 to 0.998), p=0.037). <u>PA:</u> no associations between BMI level and total amount of PA or PA intensity.

Sign. = significant; PA = physical activity; CRF = cardiorespiratory fitness; BMI = body mass index; MPA = moderate physical activity; MVPA = moderate-to-vigorous physical activity; VPA = vigorous physical activity; VVPA = very vigorous physical activity, WC = waist circumference; WHR = waist to hip ratio; LTPA = leisure-time physical activity; SSF = skinfold thickness; STF = truncal subcutaneous fat; PWC = physical work capacity

Table 1 - continued

Reference	Study design	Anthropo-metrics	Cardio-respiratory fitness	Motor fitness	Objective physical activity	Subjective physical activity	Results
Ortega (2010)	cross-sectional; age: 15 years; N=518	BMI (Moreno et al., 2006), WC, skinfold thickness	maximal cycle test	-	activity monitor	sedentary activities (TV time)	Fitness: negative association between WC and CRF (p=0.002). PA: no associations between PA parameters and WC. Fitness+ PA: no association between WC and VPA / total PA, but significant interactions with CRF (CRF and VPA: ß=0.01, p=0.005; CRF and total PA: ß=0.01; p=0.02); inverse association between WC and low CRF level and VPA (ß=-0.10; p=0.04). No sign. associations between total PA and WC (ß= -0.08; p=0.08); high fitness level: all PA parameters positively associated with WC (ß: 0.11 to 0.25; p=0.025 to p<0.001); prevalence of being overweight, having an excess of total fatness and having a high risk WC were sign. lower in the high CRF group than in the low CRF group (all p≤0.05). CRF: component of the model: moderate PA and MVPA sign. positively associated with WC (p=0.01 and p=0.03).

Sign. = significant; PA = physical activity; CRF = cardiorespiratory fitness; BMI = body mass index; MPA = moderate physical activity; MVPA = moderate-to-vigorous physical activity; VPA = vigorous physical activity; VVPA = very vigorous physical activity, WC = waist circumference; WHR = waist to hip ratio; LTPA = leisure-time physical activity; SSF = skinfold thickness; STF = truncal subcutaneous fat; PWC = physical work capacity

Table 1 - continued

Reference	Study design	Anthropo-metrics	Cardio-respiratory fitness	Motor fitness	Objective physical activity	Subjective physical activity	Results
Huotari et al. (2010)	cross-sectional; age: 13–18 years; N=558 (2001); N=717 (1976)	BMI (Cole et al., 2000)	2,000-m running test (boys), 1,500-m running test (girls)	-	-	frequency per week of PA outside school	No separate analyses for PA and CRF in relation to association with overweight, but regression model shows that LTPA (ß: 0.23 to 0.30; p<0.001) and BMI (ß: -0.10 to -0.42; p<0.001) significant predictors of CRF.
Gonzalez-Suarez and Grimmer-Somers (2011)	cross-sectional; age: 11–12 years; N=4,600	BMI (Cole et al., 2000)	shuttle run	standing broad jump, 50-m sprint	-	MVPA, physical activity score	Fitness: sign. inverse association between overweight and standing long jump (p=0.001) and overweight and CRF (p=0.001). sign. inverse association between overweight and 50-m sprint (p=0.02). Adolescents with lower median score in the standing broad jump and predicted CRF: higher odds ratio to be overweight (OR=3.1 (1.7 to 5.8) or obese (OR=9.1 (3.4 to 24.1). PA: sign. inverse association between BMI and PA score (p=0.006). Low PA: sign. higher odds ratio to be overweight or obese (overweight OR=4.6 (2.5 to 8.5), obese OR=10.8 (3.9 to 30.1).

Sign. = significant; PA = physical activity; CRF = cardiorespiratory fitness; BMI = body mass index; MPA = moderate physical activity; MVPA = moderate-to-vigorous physical activity; VPA = vigorous physical activity; VVPA = very vigorous physical activity, WC = waist circumference; WHR = waist to hip ratio; LTPA = leisure-time physical activity; SSF = skinfold thickness; STF = truncal subcutaneous fat; PWC = physical work capacity

Table 1 - continued

Reference	Study design	Anthropo-metrics	Cardio-respiratory fitness	Motor fitness	Objective physical activity	Subjective physical activity	Results
Aires et al. (2010)	longitudinal; age: 11–16 years; N=345	BMI (not categorized)	shuttle run	back saver, sit and reach, curl ups, push ups	-	sport outside school in (non) organized sport (MVPA), sedentary activities (TV, PC time)	Fitness: sign. neg. association between BMI and fitness level ($p<0.001$). High fitness level at baseline: lowest pos. changes in BMI over all measurements; low fitness at baseline: increased BMI. Low fitness level at baseline: neg. changes in total PAI; pos. changes in BMI. PA: no analyses.
He et al. (2011)	longitudinal; age: 8–13 years (T1); T2: 18 month later N= 2,179 (T1); N=1,795 (T2)	BMI (Ji, 2005)	shuttle run	-	-	categorized into physical active / inactive	Fitness: CRF: sign. inverse correlation with BMI in both surveys ($r=-0.73$ and $r=-0.74$; $p<0.001$): CRF inversely associated with the changes in BMI over the study period ($ß=-0.63$; $p<0.001$). Sign. higher CRF in normal weight or in physically active children ($p<0.001$). PA: no sign. associations between PA and the changes in BMI.

Sign. = significant; PA = physical activity; CRF = cardiorespiratory fitness; BMI = body mass index; MPA = moderate physical activity; MVPA = moderate-to-vigorous physical activity; VPA = vigorous physical activity; VVPA = very vigorous physical activity, WC = waist circumference; WHR = waist to hip ratio; LTPA = leisure-time physical activity; SSF = skinfold thickness; STF = truncal subcutaneous fat; PWC = physical work capacity

The effects of physical activity and physical fitness on overweight and the strength of the association between physical activity, physical fitness and overweight by gender are summarized in Table 2.

We defined four categories based on the results of the statistical tests ($p>0.05$; $p<0.05$; $p<0.01$; $p<0.001$) and interpreted the associations regarding overweight: for instance, a positive relationship between fat free mass and physical activity was interpreted as a negative association between overweight and physical activity and the corresponding statistical result transcribed by the corresponding statistical result. The results in this table clearly show a stronger relationship and a more pronounced gender effect on the relationship between physical fitness and overweight than between physical activity and overweight (Table 2).

Table 2 - Overview of the strength of the different associations

Author	physical activity - overweight	gender differences	physical fitness - overweight	gender differences	Interaction PA, fitness, overweight	gender differences
Deforche et al. (2003)	0	*	3	***		
Ng et al. (2006)	0	n.a.	3	X		
Pate et al. (2006)			3	X		
Ara et al. (2007)	0	X	2	**		
Haerens et al. (2007)	1	X	3	*		
Ortega et al. (2007)	0	*	1	X	n.a. (data not shown)	n.a.
Fogelholm et al. (2008)	0	n.a.	2	X	n.a. (overweight = mediator)	X
Lohman et al. (2008)	1	n.a.	1	n.a.	1 (PA = moderator)	n.a.
Aires et al. (2010)	0	n.a.	1	n.a.		
Huotari et al. (2010)			n.a.	*	BMI & PA = predictors of CRF [a]	X
Ortega (2010)	0	n.a.	2	X	3 (CRF = moderator)	X
Gonzalez-Suarez and Grimmer-Somers (2011)	0	X	2	n.a.		
Aires et al. (2010)	1	n.a.	2	***	1 (CRF = mediator)	*
He et al. (2011)	0	***	2	***		

3=strong effect; 2=moderate effect; 1=low effect; 0=no effect; ***=large gender differences; **=middle gender differences; *=small gender differences; X=no gender differences; n.a.=not available

[a] this study did not analyze the association between PA – overweight or fitness – overweight →no information about mediator or moderator effect, so that this study was not added to interaction studies in the manuscript

Relationship between physical activity, physical fitness and overweight

Because the statistical data evaluation in the included studies was heterogeneous, the central outcomes of all studies cannot be summarized, and hence we present the results of each study. Ortega et al. (2007) reported a higher BMI in adolescents with lower cardiorespiratory fitness independent of their sedentary and leisure time activities (physical activities outside school). In boys and girls, BMI was negatively correlated with cardiorespiratory fitness independent of their leisure-time physical activity and sedentary activities (boys: $p=0.006$; girls: $p<0.001$). Similarly, cardiorespiratory fitness was inversely related to waist circumference (boys: $p=0.001$; girls: $p=0.005$) independent of physical activity. Up to 10% of variance in waist circumference in boys and 18% of variance in waist circumference in girls was explained by their sedentary activities (television viewing and video/computer time). Variability in cardiorespiratory fitness explained up to 13% of the variance in waist circumference in boys and up to 16% in girls.

In contrast, Fogelholm et al. (2008) found that variance in physical activity better explained the variability in physical fitness (ß-coefficients between -0.33 and 0.49) than that in overweight (ß-coefficients between -0.27 and 0.24). The associations between overweight and physical activity and between physical activity and physical fitness were comparable for both genders. The intensity of physical activity and being overweight predicted physical fitness in adolescents. Fogelholm et al. (2008) described that physically active persons who are overweight cannot achieve better physical fitness values because of the negative association between being overweight and physical fitness. Thus, overweight acts as a mediator for the relationship between physical activity and physical fitness.

In another study, Ortega (2010) showed that cardiorespiratory fitness influences the association between being overweight and physical activity. Hence, cardiorespiratory fitness acts as a moderator for the relationship between overweight and physical activity. The association between physical activity, physical fitness and overweight did not differ between genders. Lohman et al. (2008) reported that girls with high levels of physical activity (one standard deviation above the mean) and average body composition (fat free and fat mass) had a higher physical fitness level (+3.5%) and girls with low levels of physical activity (one standard deviation below the mean) and average body composition have a lower physical fitness level (-3.5%) compared with that of girls with average levels of physical activity and average fat free and fat mass.

Relationship between physical fitness and overweight

Table 2 shows that all studies showed an inverse relationship between physical fitness and overweight and overweight and physical fitness respectively, except for Huotari et al. (2010), where no data were available. In two studies, cardiorespiratory fitness (Deforche et al., 2003; Fogelholm et al., 2008) was more strongly related to overweight than motor fitness, and two studies (Ara et al., 2007; Gonzalez-Suarez & Grimmer-Somers, 2011) showed a stronger relationship between BMI and cardiorespiratory fitness than between BMI and motor fitness. Interpreting and comparing these results is difficult because these studies used different analytic strategies and measurement instruments. The four studies (Aires et al., 2010; Deforche et al., 2003; Fogelholm et al., 2008; Gonzalez-Suarez & Grimmer-Somers, 2011) used three to seven different tests for measuring several aspects of motor capacity.

All twelve studies reported an inverse relationship between cardiorespiratory fitness and overweight. Seven studies (Aires et al., 2010; Ara et al., 2007; Deforche et al., 2003; Fogelholm et al., 2008; Gonzalez-Suarez & Grimmer-Somers, 2011; Ng et al., 2006; Ortega et al., 2007) used shuttle run tests, and one study each used the cooper test (Haerens et al., 2007), a submaximal treadmill test (Pate et al., 2006), the PWC 170 (Lohman et al., 2008), the maximal cycle test (Ortega, 2010) or the 2000-m (boys) and 1500-m (girls) running test for assessing cardiorespiratory fitness.

Pate et al. (2006) found no difference in the relationship between physical fitness and BMI between genders, and Ortega et al. (2007) observed a similar relationship between overweight and physical fitness for both genders. In addition, BMI adjusted by waist circumference was significantly negatively associated with cardiorespiratory fitness only in overweight boys ($p \leq 0.05$) but not in normal weight adolescents and overweight girls. Cardiorespiratory fitness was inversely associated with BMI in boys and in girls ($p<0.001$) and with waist circumference (boys: $p=0.001$; girls: $p=0.005$). Variance in cardiorespiratory fitness explained up to 13% of variability in waist circumference in boys and up to 16% in girls. In addition, the comparison of cohorts collected in 1976 and 2001 by Huotari et al. (2010) confirmed these findings. In girls, the influence of BMI on cardiorespiratory fitness was smaller (ß=-0.42, $p<0.001$, $R^2=0.165$) than that in boys (ß=-0.36, $p<0.001$, $R^2=0.127$) in the 2001 study. In comparison, in the 1976 study no significant relationship between BMI and cardiorespiratory fitness was found for girls or boys. The results by Gonzalez-Suarez and Grimmer-Somers (2011) were not stratified by gender. Fogelholm et al. (2008) did not find significant differences in ß-coefficients for endurance capacity between genders.

Ara et al. (2007) reported that skinfold thickness was most strongly related to cardiorespiratory fitness in both boys and girls, and the ß-coefficient for this relationship was greater in boys (ß=-3.334; p<0.001) than in girls (ß=-2.571; p<0.001). The next strongest predictors of cardiorespiratory fitness were truncal subcutaneous fat (boys: ß=-1.78, p<0.001; girls: ß=-1.77, p<0.001) and BMI (boys: ß=-0.047, p<0.001; girls: ß=-0.059, p<0.001).

The results by Deforche et al. (2003) are comparable to those reported by Aires et al. (2010), and the endurance capacity in obese boys was higher than that in obese girls (F=22.5; p<0.001). Haerens et al. (2007) analysed the difference in overweight and cardiorespiratory fitness by gender and detected a significant (F=6.08; p≤0.05) difference in running capacity between overweight boys and girls. Ortega (2010) reported an inverse association between waist circumference and cardiorespiratory fitness without a significant gender effect. Fogelholm et al. (2008) showed marginally stronger relationships between ball skills ($ß_{boys}$=-.12, p<0.001; $ß_{girls}$=-0.10, p=0.003), jumping back and forth ($ß_{boys}$=-0.17, p<0.001; $ß_{girls}$=-0.14, p<0.001) and five-jump ($ß_{boys}$=-0.27, p<0.001; $ß_{girls}$=-0.26, p<0.001) and overweight in boys than in girls. In comparison, the influence of overweight on number of sit-ups ($ß_{boys}$=-0.20, p<0.001; $ß_{girls}$=-0.21, p<0.001) and the coordination test ($ß_{boys}$=-0.22, p<0.001; $ß_{girls}$=-0.24, p<0.001) was stronger in girls than in boys. Deforche et al. (2003) found a significant interaction between gender and obesity in the sit and reach test (F=4.3; p<0.05), bent-arm-hang (F=45.8; p<0.001) and endurance shuttle run (F=22.5; p<0.001). Ng et al. (Ng et al., 2006) did not stratify weight groups by gender, Lohman et al. (2008) only included females in their study, and Gonzalez-Suarez and Grimmer-Somers (2011) did not perform a separate analysis of the relationship between overweight and motor fitness for genders.

Relationship between physical activity and overweight

In comparison to physical fitness, the relationship between physical activity and overweight is less clear (see additional file 2). Three studies collected physical activity data but did not analyse the relation between physical activity and overweight (Fogelholm et al., 2008; Huotari et al., 2010; R. R. Pate et al., 2006). Six studies did not find any relationships between overweight and physical activity (Aires et al., 2010; Ara et al., 2007; Deforche et al., 2003; Ng et al., 2006; Ogden, 2010; Ortega et al., 2007). Two studies (Gonzalez-Suarez & Grimmer-Somers, 2011; Lohman et al., 2008) analysed relations between physical activity and overweight and between overweight and physical activity, respectively. Lohman et al. (2008) found a negative significant correlation between BMI and physical activity, whereas Gonzalez-Suarez and Grimmer-Somers (2011) did not find differences between BMI and physical activity scores in overweight and normal youth.

Objective and subjective measurement instruments yielded comparable results. While one study detected a relationship between objectively measured physical activity and overweight (Lohman et al., 2008), two studies did not find any relationship between overweight and objectively measured physical activity (Aires et al., 2010; Ng et al., 2006). We found similar results for studies using subjective measurement instruments. One study reported a significant relationship between overweight and subjectively measured physical activity (Gonzalez-Suarez & Grimmer-Somers, 2011), and three studies did not find relationships between overweight and subjectively measured physical activity (Ara et al., 2007; Ortega et al., 2007) and subjectively measured physical activity and overweight (Deforche et al., 2003). Two studies (Haerens et al., 2007; Ortega, 2010) used both objective and subjective instruments for assessing physical activity. While Ortega (2010) did not find any relationship between overweight and physical activity, Haerens et al. (2007) detected significant relationships between overweight and physical activity dependent of the method of data evaluation. Similarly, categorized physical activity (active versus non-active) was not related to overweight (Ara et al., 2007). In comparison, the intensity of physical activity was related to overweight (Aires et al., 2010; Haerens et al., 2007).

Five studies (Ara et al., 2007; Deforche et al., 2003; Gonzalez-Suarez & Grimmer-Somers, 2011; Haerens et al., 2007; Ortega et al., 2007) analysed differences in the relationship between physical activity and overweight between genders. Two studies (Ara et al., 2007; Ortega et al., 2007) found a stronger relationship between physical activity and overweight for boys than for girls. In contrast, three studies (Deforche et al., 2003; Gonzalez-Suarez & Grimmer-Somers, 2011; Haerens et al., 2007) did not find a gender effect on the relationship between (total) physical activity and overweight. Ortega et al. (2007) performed separate median value comparisons between BMI and waist circumference, and activity pattern and cardiorespiratory fitness by gender. The strongest relationship in boys ($p=0.006$) was that between waist circumference and sedentary activities was. In girls, the strongest association was that between waist circumference and active commuting to school (no information was provided on type of active commuting; $p=0.002$). A significant relationship between BMI and sedentary activities (≤ 2 hours; $ß=-0.72$; $p=0.043$) was found only in boys, whereas waist circumference was negatively associated with sedentary activities (≤ 2 hours) in boys ($ß=-2.46$; $p=0.024$) and in girls ($ß=-1.47$; $p=0.028$). Up to 10% of variance in waist circumference in boys and up to 18% in girls were explained by variability in sedentary activities. In contrast, Gonzalez-Suarez and Grimmer-Somers (2011) did not find an effect of gender on the relationship between being overweight and physical activity. Ara et al. (2007) analysed the differences in weight (measured using various methods) between active and non-active adolescents. BMI was higher in active boys than in non-active boys ($p=0.05$), and the sum of skin fold test scores was slightly higher in active than in non-active boys. In contrast, while fat mass was lower in active girls than in non-active girls ($p<0.05$), both groups had comparable BMI. Deforche et al. (2003) reported a higher sport index in non-obese boys compared to obese boys ($F=3.7$; $p<0.05$), and a comparable sport index in obese and non-obese girls. Aires et al. (2010) did not report a gender specific analysis. Haerens et al. (2007) did not find significant differences between body weight groups in objectively ($F=0.08$; $p>0.05$) or subjectively ($F=0.03$; $p>0.05$) measured total physical activity analysed by gender. However, moderate physical activity significantly differed between boys and girls ($F=4.25$; $p\leq0.001$). The results for overfat (measured via skinfold thickness) and normal fat boys and girls were comparable. Objectively ($F= 0.47$; $p>0.05$) and subjectively ($F=2.13$; $p>0.05$) measured total physical activity, light physical activity ($F= 0.18$; $p>0.05$) and moderate physical activity ($F=1.4$; $p>0.05$) did not differ significantly between overfat and normal fat boys and girls.

Associations between physical activity, fitness and overweight in longitudinal studies

Two longitudinal studies captured physical activity, physical fitness and overweight.

Relationship between physical activity, physical fitness and overweight

Both longitudinal studies (Aires et al., 2010; He et al., 2011) analysed only the relationship between physical activity and overweight and between physical fitness and overweight and not the interaction among all three parameters. However, separate analyses by Aires et al. (2010) showed that while physical activity influenced cardiorespiratory fitness and cardiorespiratory fitness influenced BMI, BMI was not related to physical activity. Therefore cardiorespiratory fitness acts as a mediator in the relationship between physical activity and BMI.

Relationship between physical fitness and overweight

He et al. (2011) and Aires et al. (2010) reported an inverse relationship between BMI and physical fitness and between physical fitness and BMI respectively. Subjects with a low fitness level at baseline had a higher risk of becoming overweight or obese compared to those who had high initial fitness levels (data not shown) (He et al., 2011).

Aires et al. (2010) did not report a potential gender difference. In contrast, He et al. (2011) found that boys with low fitness at baseline were more likely to be overweight 3-years later than girls (boys: $OR=8.71$, $p<0.001$; girls: $OR=6.87$, $p=0.055$).

Relationship between physical activity and overweight

The questionnaire used by Aires et al. (2010) provided information on sedentary activities. Adolescents with low physical activity levels did not experience a significant increase in BMI over time (Aires et al., 2010). Similarly, He et al. (2011) did not reveal significant associations between changes in BMI and physical activity. None of the studies investigated the influence of gender on the relationship between physical activity and overweight.

Discussion

The purpose of this systematic review was to provide an overview of cross-sectional and longitudinal studies published in or after 2000 on physical activity, physical fitness and overweight in adolescents, and to identify mediator and moderator effects in the interrelationship among these three parameters particularly considering gender differences. Objectivity of self-reported physical activity has been questioned because of potential over- or underestimation (Lohman et al., 2008) and thus should be considered with caution. However, because only few studies examined the interaction between physical activity, physical fitness and overweight, we combined results of objectively and subjectively assessed physical activity.

To the best of our knowledge, this article is the first review on the interrelationship between physical activity, physical fitness and overweight, and hence our results cannot be related to the literature or to other study populations. Synthesizing the interaction between all three parameters was difficult because only four studies specifically investigated this interaction. While the literature reported inconsistent results, all studies showed an interaction between these parameters. Several studies (Fogelholm et al., 2008; Lohman et al., 2008; Ortega, 2010; Ortega et al., 2007) confirmed that physical activity and physical fitness are equally important for health (Brandes, 2012). In the following the results will be discussed with reviews analysing only the relationship between two parameters, because no comparable reviews (reviews analysing the interaction) were found.

The different strengths of the correlations between the three parameters may be at least in part attributed to the different measurements of physical activity. For instance, two studies (Fogelholm et al., 2008; Ortega et al., 2007) assessed physical activity via questionnaire, one via accelerometer (Lohman et al., 2008) and one via activity monitor and questionnaire (Ortega, 2010), and the collection period of objectively measured physical activity ranged from three (Ortega, 2010) to six (Lohman et al., 2008) days. In addition, the two studies that measured physical activity subjectively omitted reporting details on their measurement instruments. Further, Ortega et al. (2007) measured physical activity outside of school for only four days. While Fogelholm et al. (2008) measured the activity during leisure-time in and outside of sports clubs, they only reported frequency and duration and not intensity or setting of physical activity. Hence, reliable and valid questionnaires assessing frequency, duration, intensity and setting of the different physical activities are still needed (World Health Organisation, 2012) especially because, for instance, intensity is an important aspect in overweight prevention (Winkler, Hebestreit, & Ahrens, 2012). Interestingly, studies that used unspecific measurement instruments for physical activity reported weak or no relationships between physical activity and overweight (Ara et al., 2007; Ortega, 2010; Ortega et al., 2007). The poor quality of physical activity measurement instruments may also explain the stronger influence of cardiorespiratory fitness than that of physical activity on overweight. The main limitation of subjective measurement instruments is potential over- and underestimation of physical activity (Lohman et al., 2008). In comparison, objective measurement instruments for physical activity can only capture specific activities and require a high effort by the participants. For instance, subjects have to regularly wear the accelerometers or pedometers for extended periods of time and on different days.

The data on the relationship between physical activity and overweight are inconsistent. Specifically, the different levels of physical activity (measured by objective measurement methods) showed different relationships to overweight. In addition, the effect of gender on the relationship between physical activity and overweight was inconsistent. While Deforche et al. (2003), Haerens et al. (2007) and Gonzalez-Suarez and Grimmer-Somers (2011) reported no gender effect on the relationship between overweight and physical activity, other studies (Ara et al., 2007; Ortega et al., 2007) revealed that gender affected the relationship between overweight and physical activity but that this association depended on the anthropometric measurement method used to measure overweight. Similar to our observations in adolescents, Must and Tybor (2005) found inconsistent results in children with a higher tendency to an inverse relationship between physical activity level and overweight in *cross-sectional studies* and differences in the relationship between physical activity and overweight between boys and girls emphasizing the inconsistent state of research not only in adolescents but also in children. The previously discussed large number and poor quality of methods for measuring physical activity might explain this observation. In addition, these results show that capturing physical activity in youth is difficult. In a review of cross-sectional studies that analysed self-reported and objectively measured physical activity in overweight children and adolescents, Winkler et al. (2012) reported inconsistent results and that the intensity of physical activity played a critical role independent of age and gender. In addition, Winkler et al. (2012) reported that physical activity was related to overweight in two *longitudinal studies*, which contradicts the results of the two longitudinal studies (Aires et al., 2010; He et al., 2011) included in our review that found no relationships between physical activity and overweight. In contrast, Must and Tybor (2005) reviewed longitudinal studies and reported comparable results to our findings in longitudinal studies. Similarly to adolescents, the results in children are inconsistent and low physical activity level was not related to changes in BMI (Aires et al., 2010; He et al., 2011; Must & Tybor, 2005). However, according to Must and Tybor (2005), most cross-sectional and longitudinal studies showed no relationships between physical inactivity and overweight in adolescents and inconsistent gender specific results.

All studies included in our review observed inverse relationships between physical fitness and overweight. Because of the different measurement instruments for cardiorespiratory fitness used in these studies (shuttle run: (Aires et al., 2010; Aires et al., 2010; Ara et al., 2007; Deforche et al., 2003; Fogelholm et al., 2008; Gonzalez-Suarez & Grimmer-Somers, 2011; He et al., 2011; Ng et al., 2006; Ortega et al., 2007), maximal treadmill test: (Pate et al., 2006), maximal cycle test: (Ortega, 2010), cooper test: (Haerens et al., 2007), PWC 170: (Lohman et al., 2008), 2,000/1,500m: (Huotari et al., 2010)), final comparisons are difficult. Adolescents with lower cardiorespiratory fitness were more likely to be overweight or obese than those with high cardiorespiratory fitness (Aires et al., 2010; Ara et al., 2007; Deforche et al., 2003; Fogelholm et al., 2008; Gonzalez-Suarez & Grimmer-Somers, 2011; Haerens et al., 2007; He et al., 2011; Lohman et al., 2008; Ng et al., 2006; Ortega, 2010; Ortega et al., 2007; Pate et al., 2006). However, gender influenced the relationship between overweight and cardiorespiratory fitness. These results are in agreement with the results of other studies including those reported by Ostojic, Stojanovic, Stojanovic, Maric, and Njaradi (2011). Similar results were observed for motor fitness and overweight. The measurement instruments were also inconsistent in motor fitness (Eurofit (Ara et al., 2007; Deforche et al., 2003): two studies; unknown (Fogelholm et al., 2008; Gonzalez-Suarez & Grimmer-Somers, 2011):

two studies). While motor fitness in overweight and obese adolescents was lower than that in normal weight adolescents (Aires et al., 2010; Ara et al., 2007; Deforche et al., 2003; Fogelholm et al., 2008; Gonzalez-Suarez & Grimmer-Somers, 2011), the influence of gender on the relationship between motor fitness and overweight was heterogeneous.

Interestingly, some studies (Aires et al., 2010; Deforche et al., 2003; Fogelholm et al., 2008; Huotari et al., 2010; Lohman et al., 2008; Pate, Wang, Dowda, Farrell, & O`Neill, 2006) included weight as independent parameter in their statistical models while other studies (Aires et al., 2010; Ara et al., 2007; Gonzalez-Suarez & Grimmer-Somers, 2011; Haerens et al., 2007; He et al., 2011; Ng et al., 2006; Ortega, 2010; Ortega et al., 2007) used weight as dependent parameter. This observation illustrates that the causality between physical activity and overweight and between physical fitness and overweight is still unclear. For instance, Metcalf et al. (2011) suggested that overweight influences level of physical activity but not vice versa. Similar data for the causal relationship between physical fitness and overweight are not available. Hence, future longitudinal studies are warranted to tease out this causal relationship. Furthermore, additional longitudinal analyses are necessary to determine the interrelationship (mediator or moderator effect) between physical activity, physical fitness and overweight which has important implications for public health policy making and developing optimal obesity prevention or treatment programs.

Limitations

Because of the small number of studies the results were not categorized based on objective or subjective physical activity measurement. In addition, studies on metabolic syndrome or cardiovascular diseases were not included (even if physical activity, physical fitness and overweight measures were used), and only studies with the primary goal of analysing the relationship between the three parameters were included.

Conclusion

The small number of longitudinal studies emphasizes the deficit of longitudinal research, and further prospective studies are necessary for determining cause and effect and the type (correlation, mediator and moderator effect) of the interrelationship among physical activity, physical fitness and overweight.

Overall, a concluding evaluation is difficult because several studies did not state effect or effect size and hence the reported information on significant relationships should be interpreted with caution. In addition, the studies used different methods to measure physical activity, and the objectivity of self-reported physical activity is questionable (Melanson & Freedson, 1996) and may result in over- or underestimation (Lohman et al., 2008).

With this study, Step 2 of Figure 2 and Pathway 1 of Figure 4 were fulfilled. The main goal of this study was to give an overview of the current state of research about physical activity, physical fitness and overweight in youth and young adults. The analyses revealed a deficit in longitudinal, European studies analysing physical activity, physical fitness and health. The “Motorik-Modul (MoMo) Longitudinal Study: physical fitness and physical activity as determinants of health development in German children and adolescents” made a contribution towards reducing this deficit. This study is a module of the “German Health Interview and Examination Survey for Children and Adolescents” (KiGGS) which aims at long-term improvement in the health of German children and adolescents by focusing on the impact of physical fitness and physical activity (among other factors) on health (Wagner et al., 2013).

Based on the model of Hallal et al. (2006), , the model analysing Model analysing the cross-sectional and longitudinal relationship between physical activity and health (Figure 4) and because of the complexity in the further studies, the focus was placed on physical activity. In a first step, the development of physical activity (Pathway 2, Figure 4) was analysed before the longitudinal relationships between physical activity and health (Pathway 3, Figure 4) were considered in further step.

4 Longitudinal consideration of physical activity among German adolescents

Study II: Tracking physical activity in different settings from late childhood to early adulthood in Germany: the MoMo Longitudinal Study.

Background

Although the health benefits of physical activity are well documented (Li & Siegrist, 2012), these benefits require continuous and regular participation in physical activities. A physically active lifestyle during childhood and adolescence presumably carries over into adulthood (Hallal et al., 2006) implying that physical activity interventions during childhood and adolescence would be an appropriate strategy for improving physical activity levels during adulthood. Moreover, an active lifestyle during childhood and adolescence is an important factor in preventing diseases in adulthood (Lefevre et al., 2000; Telama, Leskinen, & Yang, 1996; Twisk, Kemper, & van Mechelen, 2002). Especially because obesity, physically inactive lifestyle and poor cardiorespiratory fitness in childhood may increase the risk of health problems later in life as stated by Pahkala et al. (2012), an active lifestyle should start early in life (Hallal et al., 2006). Therefore, it is important to understand these carry-over or 'tracking' effects of physical activity from childhood through adulthood.

Twisk, Kemper, and van Mechelen (2000) have defined the term 'tracking' as the stability of a certain variable over time or the predictability of a measurement early in life for the value of the same variable later in life. Usually, tracking is expressed by test-retest-correlations representing normative stability. Normative stability will be high when individuals remain at the same relative position within the sample distribution. Mean-stability (means) and homogeneity of variances provide additional information for interpreting test-retest-correlations. Telama (2009) revealed in their review that the tracking of physical activity is mostly low (males: r=0.15 to 0.44; females: r=0.09 to 0.34) from young age to adulthood where some studies showed no significant correlations. Subsequently, five studies (Cleland, Dwyer, & Venn, 2012; Dumith et al., 2012; Jose, Blizzard, Dwyer, McKercher, & Venn, 2011; Kelly et al., 2007; Swaminathan, Selvam, Thomas, Kurpad, & Vaz, 2011) from Estonia, USA, Finland, Brazil, Australia, Belgium, Scotland and the Netherlands used intervals between measurements from 3 to 21 years to analyse mostly the normative and mean stability. The results of these studies were inconsistent with a tendency to low tracking correlations. Studies published after 2009 showed weak correlation coefficients for normative stability for overall populations (overall: r=-0.08 to 0.35) (Cleland et al., 2012; Jose et al., 2011; Kelly et al., 2007) with slightly higher correlation coefficients for girls (r=-0.07 to 0.39) than for boys (r=0.05 to 0.31) (Dumith et al., 2012; Jose et al., 2011; Kelly et al., 2007; Swaminathan et al., 2011). In addition, (in)active adolescents had higher odds ratios for growing into (in)active young adults (Cleland et al., 2012; Dumith et al., 2012; Jose et al., 2011). Most previous studies used questionnaires to assess total physical activity and did not distinguish between type, frequency, intensity and setting of physical activity. Some studies (Cleland, Ball, Magnussen, Dwyer, & Venn, 2009; Kelly et al., 2007) used also objective measures to assess frequency, intensity or steps of physical activity. However, a comparison between studies using objective and subjective measurement methods is difficult because of different reliability. Moreover, comparisons between studies are difficult because of the large variability in study population size, intervals between measurements and lumped analyses of physical activity. Hence, to date the tracking of specific aspects of physical activity especially in representative samples in European countries is largely unknown.

Therefore, the purpose of the study was to quantify tracking of leisure-time physical activity (in and outside sports clubs) for 6 years from adolescence into young adulthood in Germany.

Methods

Study design and participants

KiGGS is a longitudinal and for German children and adolescents nationally representative study (Kurth et al., 2008) conducted by the Robert Koch-institute in Berlin and approved by the Federal Office for Data Protection and by the ethics committee of the Charité University Hospital. In this study, nationwide representative data on health status of children and adolescents are collected and the development of health issues, health behaviour and health risks are monitored in a core survey and several modules (Spengler, Mess, Schmocker, & Woll, 2014). The "Motorik-Modul" (MoMo) Longitudinal Study is one of these modules (Kurth et al., 2008; Woll, Kurth, Opper, Worth, & Bös, 2011) and aims to analyse the development of physical fitness and physical activity, and the impact of physical fitness and physical activity on mental and physical health (M. O. Wagner et al., 2013). The MoMo Longitudinal Study was approved by the ethics committee of University of Konstanz and has been performed according to the Declaration of Helsinki. The MoMo participants were recruited from the KiGGS sample. The sampling procedure was based on a three-step process developed in cooperation with the Centre for Survey Research and

Methodology (ZUMA, Mannheim, Germany) (Kurth et al., 2008). Based on an appropriate computation, first the study sample points (N=167) were determined. At the second stage, an age-stratified sample of randomly selected children and adolescents was drawn from local population registries for the "KiGGS Study" with a total of 28,400 participants aged 0 to 17 years (Kamtsiuris, Lange, & Schaffrath Rosario, 2007; Kurth et al., 2008). From these 28,400 participants, 17,641 youths took part in the "KiGGS Study" (response rate: 62.1%) (Jekauc, Reimers, Wagner, & Woll, 2012). In a third stage, the Robert Koch-institute has drawn the representative subsample aged between 4 and 17 years, (N=7,866) for the MoMo Study in consultation with ZUMA (Woll et al., 2011). 4,529 participants took part in the MoMo Study (response rate: 57.6%). To ensure the representativeness, weighting procedures were used (Jekauc, Reimers, et al., 2012).

In this study, we used a subsample of the MoMo Longitudinal Study. Prior to study participation, each parent and participant gave informed written consent. From 2003 to 2006, data of 4,529 children and adolescents aged between 4 and 17 years were collected in a nationwide representative sample (study baseline, t_0). From 2009 to 2012, the first survey wave (t_1) was conducted. Overall, cross-sectional data of 4,529 and longitudinal data of 2,842 children, adolescents and young adults, aged between 4 to 23 years were surveyed in the first wave. Data collection was conducted year-round without any interruptions over a longer period. Because the participants gave information in which months they participated in sports, the impact of seasonality could be excluded from the indices. In addition, the order of data collection on the 167 sample points and the time of year (season) were similar at wave 1 and baseline. Hence, an impact of seasonality can be precluded (Lange et al., 2014).

Detailed information on the study design has been previously published (Wagner et al., 2013). In this study, only longitudinal data for participants aged 11 to 17 years at baseline were included in the analysis ($N_{overall}$=947; N_{boys}=447; N_{girls}=500). MoMo longitudinal data are available upon request (alexander.woll@kit.edu).

Outcome measure

Physical activity was measured using the MoMo Physical Activity Questionnaire (MoMo-PAQ) for adolescents (Jekauc, Wagner, Kahlert, & Woll, 2013), which assesses physical activity in different settings of physical activity (sports clubs, leisure-time, school, daily activities and overall physical activity). Beside frequency, duration and intensity, the MoMo-PAQ captured data on the type of physical activity in and outside sports clubs. Up to four different physical activities could be mentioned. For the analyses of agreement all information at t_0 and t_1 were matched, proofing if at both measurement points the same information were given. The MoMo-PAQ has satisfying and similar reliability and validity as other questionnaires for measuring physical activity in adolescents (Jekauc et al., 2013). The reliability of assessing physical activity on the index level for one-week inter-test interval (ICC=intraclass correlation) was between r_{ICC}=0.60 (p<0.01) and r_{ICC}=0.74 (p<0.01) (Jekauc et al., 2013). The ICC for overall physical activity was r=0.74 (p<0.01), for sports club physical activity r_{ICC}=0.64 (p<0.01) and for leisure-time physical activity r_{ICC}=0.69 (p<0.01). The validity (compared to Actigraph GT1M and the Previous Day Physical Activity Recall) was r=0.24 (p<0.01) and r=0.43 (p<0.01) for overall activity, r=0.35

($p<0.01$) and $r=0.55$ ($p<0.01$) for sports club physical activity, and $r=0.10$ and $r=0.32$ ($p<0.01$) for leisure-time physical activity, respectively (Jekauc et al., 2013).

In this study, we only considered sports club and leisure-time activities because in Germany physical activity of adolescents and young adults largely takes place in organised sports clubs. In addition, both aspects were assessed using the same instrument for both age groups at both sampling points.

Sports club physical activity (SCPA) was assessed by four items: type of club sports activity, duration (minutes per session) and frequency (times per week) of each club sports activity, and time of the year (month) of each club sports activity. These items were combined in a club sports activity index reflecting active minutes per week at sports clubs:

Club sports index = (duration*frequency*number of month)/(12 months)

Leisure-time physical activity (LTPA) was assessed by three items: type of leisure-time physical activity, duration (minutes per week) of each leisure-time physical activity, and time of the year (month) of each leisure-time physical activity. These items were combined in the leisure-time physical activity index reflecting active minutes per week at leisure time:

Leisure-time physical activity index = (duration*number of months)/(12 months)

The **overall sports index** (OS index) was calculated by adding club sports activity and leisure-time activity index.

Overall physical activity (OPA) was assessed using a two-item questionnaire (Prochaska, Sallis, & Long, 2001) capturing information on numbers of days during the last seven days (Item 1) and during a typical week (Item 2) of moderate physical activity of at least 60 minutes per day (not considering physical education classes). The mean of these two items combines to a scale reflecting the days per week with moderate physical activity of one hour or more according to international recommendations.

In order to estimate the change and stability of the compliance with physical activity recommendations two groups were formed (fulfilled/ not fulfilled). The recommendation claims that children and adolescents aged between 5 and 17 years should perform at least 60 minutes of moderate to vigorous physical activity (of 5 to 8 metabolic equivalent of task) (World Health Organisation, 2013).

Sociodemographic predictors

Sex, age and socioeconomic status (SES) were included as determinants in the analysis. Two age groups were defined for each measurement point: t_0: 11 to 13 years (young) and 14 to 17 years (old); t_1: 17 to 19 years (young) and 20 to 23 years (old). Socioeconomic status was assessed by a parent questionnaire asking parental educational and professional status and total income of the family household (Lampert, Schenk, & Stolzenberg, 2002) and categorized into three categories low, middle and high (Winkler & Stolzenberg, 1999).

Statistical analyses

All statistical tests were conducted using IBM SPSS 21 (IBM Corporation, Armonk, NY). The study sample was described using descriptive analyses. The tracking of physical activity between baseline and wave 1 was analysed in different ways. First, Spearman's rank-correlations were calculated to track physical activity of the participants. Second, analyses of variance with repeated measurement were used to examine the mean stability (means). Fisher`s Z transformation was used to compare the Spearman's rank-order correlations between the different indices.

Kappa values were analysed for categorical variables to detect agreement between both measurement points. Outliers were detected using three standard deviations of the physical active participants and excluded from further analyses. 110 cases were identified with data for club sports activity and leisure-time physical activity. Only participants with sports club membership at t_0 and t_1 were considered for sports club activity. The level of significance was set a priori to α=.05 for all statistical tests.

Dealing with missing data is very important in empirical studies because missing data often lead to bias in parametric rating or to small sample sizes (Jekauc, Völkle, Lämmle, & Woll, 2012). Methods for dealing with *unit-nonresponse* and *item-nonresponse* were used to accommodate for these circumstances. Unit-nonresponse was treated by creating a weighting procedure to account for potential bias in outcome variables caused by selective unit-nonresponse (drop-out bias) (Kamtsiuris, Lange, & Schaffrath Rosario, 2007). In a first step, initial design weights for the baseline sample were defined using information on the probability of selection of the measurement point and the participant within the measurement point.

Subsequent data stratification ensured representativeness to the target population (German children and adolescents aged 4-17 years) regarding sex, age, region, migration background and education level. Based on these initial weights, weighted logistic regressions were performed to predict the probability of participation in wave 1. In the process, baseline data of wave 1 responders and nonresponders were used to estimate differences between wave 1 responders and the baseline sample. All longitudinal participants were assigned an individual weight according to the inverse of their probability of participation (inverse probability weighting). Expected differences between wave 1 responders and nonresponders in different variables of interest were identified, and these differences were eliminated by the weighting procedure.

For item nonresponse, the Little’s missing completely at random test (Little, 1988) revealed that data was missing in a systematic way (χ^2=1,091, df=581, $p<.001$) on item level among participants suggesting that deletion procedures would yield biased estimates (Schaffer & Graham, 2002). The amount of missing data due to item-nonresponse was low and ranged from 0.3% and 7.6% for all variables. Regression imputations were used to treat missing data due to item-non-response.

Results

Stability of means

Leisure-time physical activity (minutes per week)

Overall LTPA changed significantly from baseline to wave 1 ($F_{1,397}$=7.9, df=1, p=0.005; tables 3 and 4). The change in LTPA over time was greater for the young group than for the old group ($F_{1,397}$=10.5, df=1, p=0.001). The young group had significantly lower LTPA at t_1 than at t_0 (F_{123}=6.5, df=1, p=0.012) while in the old group LPTA remained nearly unchanged ($F_{1,346}$=0.0, df=1, p=0.890). A significant interaction in LPTA between age, sex and SES was observed ($F_{1,397}$=5.8, df=2, p=0.003).

Sport club physical activity (minutes per week)

Mean SCPA increased significantly from baseline to wave 1 (F_{387}=4.8, df=1, p=0.030; Tables 3 and 4). Age was the only determinant that significantly affected the change in SCPA over time (F_{387}=6.3, df=1, p<0.012). In addition, a significant interaction in SCPA between time, age, SES was observed (F_{387}=3.2, df=2, p=0.043). While the young group showed greater SCPA over the time independent of SES, subjects with high SES showed lower SCPA and those with low or middle SES showed higher SCPA over time. SCPA decreased by 21.8 minutes per week from t_0 to t_1 in the young group (F_{55}=17.4, df=1, p<0.001).

Overall physical activity (days per week)

Mean OPA decreased significantly from baseline to wave 1 ($F_{1,441}$=7.7, df=1, p=0.005; Tables 3 and 4). The analyses revealed a significant age ($F_{1,441}$=5.9, df=1, p=0.015) and SES effect ($F_{1,441}$=8.2, df=2, p<0.001). The young group (F_{126}=10.3, df=1, p=0.002) and the old group ($F_{1,346}$=3.7, df=1, p=0.054) had significant lower OPA at t_1 than at t_0. The post hoc test (Scheffé) showed that participants with a middle SES had a significantly higher OPA than those with a high SES A significant interaction between SES and time was found. According to the post hoc test (Scheffé), participants with a middle SES greater change in OPA than those with a high SES (middle difference: 0.219, p=0.05, CI=.000/.438). Participants with a middle or high SES had a significant decrease in OPA from t_0 to t_1. OPA increased significantly in boys but not in girls (Table 3).

Overall sports index (minutes per week)

Mean overall OS index did not change significantly from baseline to wave 1 (F_{371}=3.2, df=1, p=0.074; Tables 3 and 4). No significant interactions between OS index and sociodemographic predictors were detected.

*Table 3 - Mean (1 standard deviation) patient characteristics (*p<0.05).*

		LTPA (min./week)	**SCPA** (min./week)	**OPA** (days/week)	**OS index** (min./week)
		indices – t_0			
overall		74.1 ± 98.0 N=924	218.6 ± 122.8 N=296	3.47 ± 1.82 N=947	292.7 ± 164.5 N=932
sex	boys	81.3 ± 107.0 N=438	231.1 ± 124.2 N=168	3.78 ± 1.80 N=447	312.4 ± 171.0 N=438
	girls	67.3 ± 88.1 N=496	200.5 ± 118.6 N=128	3.15 ± 1.78 N=500	267.8 ± 151.2 N=494
age	young group	86.4 ± 104.5 N=116	112.6 ± 112.8 N=55	3.82 ± 1.75 N=117	199.0 ± 145.3 N=117
	old group	72.9 ± 97.3 N=818	107.9 ± 135.0 N=241	3.43 ± 1.82 N=830	180.0 ± 179.6 N=815
SES	low	64.5 ± 101.4 N=185	189.3 ± 107.1 N=39	3.29 ± 1.91 N=186	253.8 ± 134.6 N=184
	middle	81.9 ± 100.6 N=485	224.6 ± 120.7 N=166	3.70 ± 1.76 N=494	306.5 ± 170.6 N=483
	high	69.6 ± 89.8 N=262	222.0 ± 133.1 N=91	3.15 ± 1.78 N=265	291.6 ± 158.6 N=263
		indices – t_1			
overall		74.1 ± 93.5	222.2 ± 133.1	3.31 ± 1.86	296.3 ± 163.2
sex	boys	82.6 ± 102.1	250.5 ± 132.9	3.48 ± 1.85	333.1 ± 165.3
	girls	64.2 ± 83.5	181.0 ± 122.6	3.15 ± 1.87	245.2 ± 147.2
age	young group	58.6 ± 87.2	134.4 ± 168.0	3.20 ± 1.79	193.0 ± 170.2
	old group	74.6 ± 93.9	72.3 ± 5.4	3.32 ± 1.87	146.9 ± 162.3
SES	low	64.2 ± 96.9	230.0 ± 109.3	3.22 ± 1.83	294.2 ± 146.4
	middle	73.3 ± 89.4	231.5 ± 132.2	3.30 ± 1.88	304.8 ± 159.5
	high	82.2 ± 97.0	199.0 ± 144.5	3.38 ± 1.88	281.2 ± 177.9
		indices – t_1-t_0			
overall		-0.03 ± 128.46	-3.57 ± 155.65	0.16 ± 2.30*	-3.6 ± 192.2*
sex	boys	-1.34 ± 141.59	-19.37 ± 161.68	0.30 ± 2.31*	-20.7 ± 206.4*
	girls	3.05 ± 114.70	19.43 ± 143.84	0.00 ± 2.28	22.6 ± 167.7*
age	young group	27.89 ± 139.01*	-21.84 ± 140.89	0.62 ± 2.10*	6.0 ± 183.0
	old group	-1.67 ± 127.16	35.67 ± 154.33	0.11 ± 2.32	33.1 ± 192.9*
SES	low	0.27 ± 138.53	-40.70 ± 115.00*	0.07 ± 2.12	-40.4 ± 176.7*
	middle	8.62 ± 125.98	-6.90 ± 151.05	0.40 ± 2.40*	1.7 ± 186.8
	high	-13.75 ± 124.12	22.96 ± 178.53	-0.23 ± 2.25*	10.4 ± 202.3*

SES – socioeconomic status; LTPA – leisure-time PA; SCPA – sport club PA; OPA – overall PA; OS index – overall sports index. Only subjects with data for baseline and wave 1 were included in the analysis, and hence the number of subjects at t_0 and t_1 are the same.

Table 4 - Results of ANOVA with repeated measurements

Index	Source	Type III sum of squares	df	Mean square	F	p
LTPA (min./ week)	time	64716.3	1	64716.3	7.9	0.005
	time*sex	12211.3	1	12211.3	1.5	0.223
	time*age	86628.4	1	86628.4	10.5	0.001
	time*SES	13236.2	2	6618.1	.8	0.447
	time*sex*age	23309.3	1	23309.3	2.8	0.092
	time*sex*SES	42984.8	2	21492.4	2.6	0.074
	time*age*SES	40840.3	2	20420.2	2.5	0.084
	time*sex*age*SES	94827.2	2	47413.6	5.8	0.003
	error(time)	11340256.6	1379	8223.5		
SCPA (min./ week)	time	55058.5	1	55058.5	4.8	0.030
	time*sex	25927.2	1	25927.2	2.2	0.135
	time*age	87432.4	1	87432.4	7.6	0.006
	time*SES	10686.4	2	5343.2	.5	0.630
	time*sex*age	322.8	1	322.8	0.0	0.867
	time*sex*SES	42454.7	2	21227.4	1.8	0.160
	time*age*SES	73267.2	2	36633.6	3.2	0.043
	time*sex*age*SES	56027.5	2	28013.7	2.4	0.090
	error(time)	4465186.7	387	11538.0		
OPA (days/ week)	time	20.1	1	20.1	7.7	0.005
	time*sex	0.0	1	0.0	0.0	0.974
	time*age	15.3	1	15.3	5.9	0.015
	time*SES	42.8	2	21.4	8.2	<0.001
	time*sex*age	2.1	1	2.1	0.8	0.373
	time*sex*SES	8.9	2	4.5	1.7	0.180
	time*age*SES	12.4	2	6.2	2.4	0.093
	time*sex*age*SES	8.4	2	4.2	1.6	0.199
	error(time)	3747.1	1441	2.6		
OS index (min./ week)	time	58825.1	1	58825.1	3.2	0.074
	time*sex	2907.8	1	2907.8	0.2	0.691
	time*age	22768.8	1	22768.8	1.2	0.266
	time*SES	17939.7	2	8969.9	0.5	0.613
	time*sex*age	17924.6	1	17924.6	1.0	0.323
	time*sex*SES	1710.1	2	855.1	0.0	0.954
	time*age*SES	26708.8	2	13354.4	0.7	0.483
	time*sex*age*SES	1047.5	2	523.8	0.0	0.972
	error(time)	6798404.1	371	18324.5		

LTPA – leisure-time PA; SCPA – sport club PA; OPA – overall PA; OS index – overall sports index

Tracking

Leisure-time physical activity

The Spearman's rank-order correlation of LTPA ranged from r=-0.015 to r=0.184 representing a weak correlation for tracking physical activity from adolescence to young adulthood for LTPA independent of the determinants (Table 5). The overall correlation coefficients was r=0.094 (p<0.001). Girls had significant correlation coefficients (N=488, r=0.109, p=0.003) in LTPA while the tracking of LTPA in boys was not significant (N=427, r=0.072, p=0.061). However, the correlation coefficients did not differ between boys and girls (z=0.56, p=0.576). Spearman's rank-order correlations were significant only in the old group (old group: N=800, r=0.102, p<0.001; young group: N=115, r=0.063, p=.0494). The correlation coefficients did not differ between the young and old groups (z=0.39, p=0.697).

Spearman`s rank-order correlations were significant only for participants with a high SES (low: N= 182, r=-0.015, p=0.785; middle: N=472, r=0.075, p=0.053; high: N=259, r=0.184, p<0.001; Table 5). The correlation coefficients did not differ between the low and middle SES groups (z=1.03, p=0.303), and the middle and high SES groups (z=1.44, p=0.150). The coefficients differed significantly between the low and high SES groups (z=2.07, p=0.039). Overall, tracking of LTPA was weak for all analysed groups.

Sport club physical activity

The Spearman's rank-order correlation of SCPA ranged from r=0.194 to r=0.416 representing a higher stability than LTPA (Table 5). Weak to moderate tracking coefficients of SCPA from adolescence to young adulthood were found.

The overall tracking value was r=0.248 (p<0.001). SCPA correlated significantly in girls (N=126, r=0.239, p=0.002) and in boys (N=164, r=0.214, p=0.001). The correlation coefficients did not differ between boys and girls (z=0.22, p=0.826). Spearman's rank-order correlations were significant only in the old group (old group: N=347, r=0.254, p<0.001; young group: N=52, r=0.244, p=0.082) and did not differ significantly between age groups (z=0.07, p=0.944). Spearman's rank-order correlations were significant in all SES groups (low: N= 59, r=-0.416, p=0.001; middle: N=225, r=0.228, p=0.001; high: N=115, r=0.194, p=0.037). The correlation coefficients did not differ significantly between the low and middle SES groups (z=1.14, p=0.254), between the low and high SES groups (z=1.24, p=0.215) and between the middle and high SES groups (z=0.27, p=0.787).

Overall physical activity

OPA showed weak to moderate stability correlations (r=0.115 to r=0.371) and weakly tracked from t_0 to t_1 (r=0.211, p<0.001; Table 5). OPA had significant correlation coefficients in girls (N=500, r=0.201, p<0.001) and in boys (N=477, r=0.198, p<0.001). The correlation coefficients did not differ between boys and girls (z=0.05, p=0.960). Spearman's rank-order correlations were significant in the young (N=117, r=0.274, p=0.002) and in the old groups (N=830, r=0.208, p<0.001) with no significant differences in stability coefficients (z=0.69, p=0.490). Spearman's rank-order correlations were significant in all SES groups (low: N= 183, r=0.371, p<0.001; middle: N=477, r=0.115, p=0.002; high: N=262, r=0.224, p<0.001). The stability coefficient of OPA was significantly higher in the low SES group than in the middle SES group (z=3.55, p<0.001). The correlation coefficients did not differ between the low and high SES groups (z=1.67, p=0.095) and between the middle and high SES groups (z=1.28, p=0.201).

Overall sports index

The OS index showed moderate stability correlations (r=0.200 to r=0.332) with low to moderate strength of relation from t_0 to t_1 (r=0.266, p<0.001; Table 5). Correlation coefficients for the OS index were significant in girls (N=161, r=0.332, p<0.001) and in boys (N=222, r=0.200, p=0.003). The correlation coefficients did not differ significantly between boys and girls (z=1.36, p=0.174). Spearman's rank-order correlations were weak to moderate but not significant in the young (N=52, r=.0242, p=.083) and the old groups (N=331, r=0.275, p<0.001). Rank-order correlation coefficients did not differ significantly between age groups (z=0.23, p=0.818). Tracking values were significant in all SES groups (low: N=59, r=0.269, p=0.04; middle: N=210, r=0.301, p<0.001; high: N=119, r=0.234, p=0.012). No significant differences between the different classes of SES were found: middle and low SES (z=0.23, p=0.818), middle and high SES (z=0.27, p=0.535), low and high SES (z=0.23, p=0.818).

Correlation coefficients were significantly lower for LTPA (r=0.094) than those for OS index (r=0.266; z=4.71, p<0.001), OPA (r=0.211; z=3.19, p=0.001) and SCPA (r=0.248, z=2.79, p=0.005). OS index was more stable than the OPA (z=4.25, p<0.001) and SCPA (z=2.11, p=0.030), No differences were found for the stability between OPA and SCPA (z=0.69, p=0.490), OPA and OS index (z=1.56, p=0.119) and between OPA and SCPA (z=0.69, p=0.490).

*Table 5 - Spearman's rank-order correlation (*p<0.05)*

		LTPA (min./week)	SCPA (min./week)	OPA (days/week)	OS index (min./week)
overall		0.094*	0.248*	0.211*	0.266*
sex	boys	0.072	0.214*	0.198*	0.200*
	girls	0.109*	0.239*	0.201*	0.332*
age	young group	0.063	0.244	0.274*	0.242
	old group	0.102*	0.254*	0.208*	0.275*
SES	low	-0.015	0.416*	0.371*	0.269*
	middle	0.075	0.228*	0.115*	0.301*
	high	0.184*	0.194*	0.224*	0.234*

LTPA – leisure-time PA; SCPA – sport club PA; OPA – overall PA; OS index – overall sports index

Changes in physical activity groups

The descriptive analyses showed a negative trend, independently of setting. More persons shifted after six years from being active to inactive, independently of setting (LTPA: active-inactive: 54%, inactive-active: 46%; SCPA: member in sport club-not member in sport club: 77.1%, not member in sport club-member in sport club: 22.9%; OS index: active-inactive: 64.3%, inactive-active: 35.7%; OPA: fulfilled-unfulfilled: 58.9%, unfulfilled-fulfilled: 41.1%).

For all settings of physical activity, the analyses of agreement revealed a poor to fair strength kappa coefficient. The agreement between t_0 and t_1 of active and inactive, respectively, was 8.9% (k=0.089, p=0.001) for LTPA; 36.1% (k=0.361, p<0.001) for SCPA (member/not member); 17.6% (k=0.176, p<0.001) for OS index and 7.2% (k=0.072, p=0.005) for OPA (recommendations fulfilled/not fulfilled).

Changes in type of physical activity

SCPA showed small agreement between both measurement points (22.9%, k=0.229, p<0.001), whereas no agreement between t_0 and t_1 in LTPA was observed (k=0.000, p>0.05).

No Gender differences were found in the analyses of agreement. For girls and boys, no agreement between both measurement points was found for SCPA (k=0.000, p>0.05) and for LTPA (k=0.000, p>0.05). The analyses of agreement differed between age groups. No agreement of type in SCPA was found in the young age group (k=0.000, p>0.05) but the old age group showed an agreement of 19.8% (k=0.198, p<0.001). For LTPA no agreement were found for both age groups (k=0.000, p>0.05). The analyses of agreement did not differ between SES classes. No agreement of type in SCPA for low SES was found (k=0.000, p>0.05), for middle SES 31.2% (k=0.312, p<0.001) and for high SES 12.7% (k=0.127, p<0.001). In contrast, LTPA showed no agreement (k=0.000, p>0.05) in all SES classes.

Discussion

The aim of this nationwide representative study was to quantify tracking of leisure-time physical activity (in and outside sports clubs) for 6 years from adolescence into young adulthood in Germany. The results for overall mean stability were inconsistent. While significant changes over time in mean LTPA, SCPA and OPA were observed, OS index did not changed significantly over time. These results suggest that mean OS index is stable over 6 years from adolescence to young adulthood. Significant interactions between time and the determinants age, sex and SES were found for physical activity in all settings of physical activity. Of the analysed determinants, age had the strongest influence on stability of physical activity in different settings of physical activity.

While other studies showed higher correlation coefficients for boys (Malina, 1996), sex differences in stability of physical activity in different settings of physical activity in our study showed inconsistent results. The changes in mean SCPA and mean OPA in boys were higher than in those in girls, but the changes in mean LTPA and PA in girls were higher than those in boys. Consequently, a general statement regarding tracking physical activity in all settings of physical activity for girls and boys cannot be made. However, separate analyses by sex showed stable mean values in LTPA and SCPA for boys and in LTPA, SCPA and OPA for girls. Possible reasons for changes in physical activity in different settings of physical activity for girls and for boys include increasingly demanding school requirements (Garcia et al., 1995), the transition from school to other forms of education and the associated limited availability of time (Tappe, Duda, & Ehrnwald, 1989), relocation or changing personal interests during puberty. Similarly, Gordon-Larson and colleagues determined that young adults are in a period of changes (Gordon-Larsen, Nelson, & Popkin, 2004). Other studies showed that—especially for girls—the commitment in physical activity decreased the more demanding the physical activity is (Fuchs et al., 1988; Trost et al., 2002; van Mechelen, Twisk, Post, Snel, & Kemper, 2000). Consequently, girls invested less time per week at baseline resulting in smaller overall changes to wave 1. In addition, the support for physical activity from peers (Anderssen & Wold, 1992; McGuire, Neumark-Sztainer, & Story, 2002; Zakarian, Hovell, Hofstetter, Sallis, & Keating, 1994) and parents (Anderssen & Wold, 1992; McGuire et al., 2002; Zakarian et al., 1994) are the strongest factors for identification with physical activities (Neumark-Sztainer, Story, Hannan, Tharp, & Rex, 2003). In case of relocation this support can disappear and evoke changes in physical activity.

Changes in LTPA, SCPA and OS index did not differ between the three SES groups. However, the middle SES group showed significantly greater changes in OPA than the high SES group. These results indicate that the mean physical activity remains stable over the timespan of 6 years independent of social classes.

Stability coefficients did not differ between girls and boys supporting results reported by Herman et al. (2009). In contrast, Telama et al. (Telama, Leskinen, & Yang, 1996; Telama et al., 2005) reported lower stability of LTPA, SCPA and OPA in girls than in boys. A possible reason for these discrepancies is that girls may have other interests in their leisure time (such as fashion or music) during puberty than boys (Kientzler, 1999; Tappe et al., 1989). While for boys the competition may be important (Flintoff & Scraton, 2001), for girls the sociability played an important role (Hargreaves, 1994). Other studies observed that girls rather engage in physical activities if a same-sex friend joins them in their activity (Flintoff & Scraton, 2001). In our study, tracking coefficients were low for boys and girls. These results confirm previous reports of low tracking coefficients for LTPA, SCPA and OPA (Anderssen, Wold, & Torsheim, 2005; Janz, Dawson, & Mahoney, 2000; Telama et al., 1996; Telama et al., 2005). Hence physical activity in Adolescence and young adulthood appears to be a volatile behaviour exposed to many destabilising factors.

Rank-order coefficients did not differ between age groups. These results do not correspond to the results of the study by Telama et al. (1996) who reported highest correlations in the oldest cohort. However, in that study the young group was very small (N=55) compared to the old group (N=830). Hence, it is possible that this age difference does not fully represent true differences between groups, and hence these results should be interpreted with caution.

Differences in stability coefficients between SES groups were observed for LTPA and OPA but not for SCPA and OS indices. As expected, LTPA tracked better in the high SES groups than in the low SES group. In contrast, OPA was more stable in the low SES group than in the middle SES group. Several factors may explain these differences. It is possible that parents of the young age group with a high SES have greater (financial) resources (Dagkas & Stathi, 2007) allowing their children to participate in activities other than sports such as playing music requiring increasing time commitments as the children age. In contrast, greater financial resources enable to participate in physical activities (Dagkas & Stathi, 2007; Roberts, Cavill, Hancock, & Rutter, 2013). Another possible reason is the fact that in this study a large number of the study population relocated after finishing high school requiring reorganising physical and sports activities in the new environment.

In Germany, training in sports clubs is scheduled regularly each week on the same day and time with only minor variations between years (Telama et al., 1996). Hence, it was to expect that SCPA is more stable than physical activity outside of sports clubs (Malina, 1996). However, the results of this study showed that the stability of physical activity did not differ between settings of physical activity independently of sex, age and SES. Hence, it appears that adolescents who are physically active will not change the setting (sports club versus outside of sports clubs) of their activity as they grow into young adults. Moreover, the peer environment and a relationship of trust to the trainer may explain these results.

In general, comparing our results with those of other studies is difficult because the timespan between sampling points and the age range of study population vary largely between studies (Lefevre et al., 2000; Matton et al., 2006; Telama, 2009; Telama et al., 2005). Moreover, most studies only analysed the stability of overall physical activity. Nonetheless, our results are in agreement with those of other studies (Engström, 1991; Tammelin, Nayha, Laitinen, Rintamaki, & Jarvelin, 2003; Twisk et al., 2000) with similar study population and intervals. For instance, Twisk et al. (2000) found a stability coefficient of r=0.340 while other studies reported only rarely significant correlation coefficients but rather significant predictions or tendencies (Engström, 1991; Tammelin et al., 2003).

Results of the analyses of agreement for the type of physical activities are inconsistent. While the SCPA showed no agreement for girls and boys, the middle social class showed the highest agreement in SCPA. In addition, only the old age group showed an agreement between both measurement points which could be caused by the small number of participants in the young age group. LTPA showed no agreement for all determinants and age groups.

The correlation coefficients in our study were low which may have been related to the long timespan of 6 years between baseline and wave 1. Indeed, previous studies showed that the longer the interval is the smaller are the stability values. For instance, Herman et al. (2009) reported rank-order correlations between baseline and wave 1 (2 years interval) of r=0.540. The correlation coefficients in our study ranged from 0.094 to 0.416. Correlation coefficients in a study with a 22-year interval by Basterfield et al. (2011) were not significant. These combined results confirm that physical activity tracks better the shorter the timespan between measurements (Malina, 1996). The strength of correlations also depends on the reliability of assessing subjective information (Telama et al., 1996). Specifically, tracking correlations not only entail stability of the measurement but also its reliability. Therefore, low reliability of physical activity measures is another potential reason for the reported low test-retest-correlations. Therefore, future studies should consider using objective measures for assessing stability of physical activity from adolescence to young adulthood.

Strength and limitations

In this study, we measured physical activity in different settings in a large and representative study sample with a large age range. The focus of our study was to analyse “physical activity”. In Germany, socially conditioned, this physical activity happened mostly in sports clubs, why this aspect played an important role in the analyses. However, overall physical activity was also analysed. Because of the size of the sample, data were collected using a questionnaire that only captures subjective data. Questionnaires tend to overestimate physical activity, and the study sample tends to have difficulties to appreciate the extent (in frequency, duration and intensity) of physical activity (Lohman et al., 2008). This could lead to diverse information between the measurement points resulting in weak stability over time. Moreover, it is possible that estimated missing data over- or underestimated physical activity values. Finally, the satisfactory reliability may have resulted in lower stability coefficients thereby underestimating stability. Because of the higher reliability of objective measures, an increase of the test-retest correlation would be expected if physical activity would be gather with e.g. accelerometers.

Conclusions

In this representative study, we report on the stability of physical activity in different settings. The results showed that physical activity in different settings is not stable over time and confirmed that physical activity is a fluctuating variable. The poor stability of physical activity over time emphasize the necessity for strategies aiming at making physical activity programs more attractive to adolescents and increasing physical activity in young adults (Janz et al., 2000).

The overall goal of this study was to analyse the development of physical activity in different settings of physical activity, thus fulfilling Step 3 in Figure 2. The overall results showed that that physical activity is stable only to a low to moderate extent, depending on its setting. This begs the question, based on the extended model in Figure 4, of how these changes in physical activity are related to health. The next study therefore focused on the relationship between changes in physical activity and changes in body weight.

5 The relationship between physical activity and weight among German adolescents

Study III: Do changes in physical activity lead to changes in weight among German adolescents? Results of the MoMo Longitudinal Study.

Introduction

The prevalence of overweight and obesity is rising steadily in Western countries (World Health Organisation, 2015) and the causes are multifactorial. Aside from genetics and diet, physical activity plays a considerable role. The relationship between physical activity and overweight / obesity is well known (Centers for Disease Control and Prevention, 2015). In addition, studies (Couppe et al., 2014; Keating et al., 2014; Sanchis-Gomar et al., 2015; Verona et al., 2013) have shown that such positive relations require continuous and regular participation in physical activities. In addition, overweight and obesity in childhood can induce health restrictions (e.g. diabetes, arteriosclerosis) later in life (Weiss & Caprio, 2005). Therefore, an active lifestyle during childhood and adolescence is an important factor in preventing diseases in adulthood (Lefevre et al., 2000; Telama et al., 1996; Twisk et al., 2000) and, moreover, it is desirable that physical activity progresses from childhood into adulthood to prevent health restrictions later in life. Results of various studies in this area are heterogeneous, however there is a trend towards low to moderate stability in physical activity (Telama, 2009). The first representative German study to analyse the stability of physical activity from late childhood to early adulthood showed only weak stability of physical activity in different settings (Rauner, Jekauc, Mess, Schmidt, & Woll, 2015). This warrants the question of how the changes in physical activity over time affect changes in weight. To the best of our knowledge, no literature exists in this field. Most studies to date analysed the relationship between changes in screen time / sedentary activities and overweight (Draper, Basset, de Villiers, & Lambert, 2014; Ferrar & Golley, 2015; Pereira et al., 2015).

Therefore, the purpose of this study was to analyse for the first time the relationship between changes in physical activity over a six-year period in different settings of physical activity and changes in weight from adolescence into young adulthood in Germany. Age, sex and socioeconomic status (SES) were controlled.

Methods

Study design and participants

KiGGS is a longitudinal and nationally representative study of German children and adolescents (B. M. Kurth et al., 2008) conducted by the Robert Koch Institute in Berlin and approved by the Federal Office for Data Protection and by the ethics committee of the Charité University Hospital. In this study, nationwide representative data on the health status of children and adolescents are collected and the development of health issues, health behaviour and health risks are monitored in a core survey and in several modules (Spengler et al., 2014). The "Motorik-Modul" (MoMo) Longitudinal Study is one of these modules (Kurth et al., 2008; Woll et al., 2011) and aims to analyse the development of physical fitness and physical activity, and the impact of physical fitness and physical activity on mental and physical health (Wagner et al., 2013). The MoMo Longitudinal Study was approved by the ethics committee of the

University of Konstanz and has been performed according to the Declaration of Helsinki. Detailed information on the description of sampling can be found in Rauner et al. (Rauner et al., 2015) and Wagner et al. (Wagner et al., 2013).

In this study, a subsample of the MoMo Longitudinal Study was used. Prior to study participation, each parent and participant gave informed written consent. From 2003 to 2006, data on 4,529 children and adolescents aged between 4 and 17 years were collected in a nationwide representative sample (study baseline, t_0). From 2009 to 2012, the first survey wave (t_1) was conducted. Overall, cross-sectional data on 4,529 and longitudinal data on 2,842 children, adolescents and young adults aged between 4 and 23 years were collected in the first wave. Because the participants stated during which months they participated in sports, the impact of seasonality could be excluded from the indices. In addition, the order of data collection on the 167 sample points and the time of year (season) were similar at wave 1 and at baseline. Hence, an impact of seasonality can be precluded (Lange et al., 2014).

In this study, only longitudinal data for participants aged 11 to 17 years at baseline were included in the analysis (see table 6) ($N_{overall}$=913; N_{boys}=481; N_{girls}=432). MoMo longitudinal data are available upon request (alexander.woll@kit.edu).

Outcome measures

Physical activity

Physical activity was measured using the MoMo Physical Activity Questionnaire (MoMo-PAQ) for adolescents (Jekauc et al., 2013), which assesses physical activity in different settings (sports clubs, leisure-time, school, daily activities and overall physical activity). The MoMo-PAQ has satisfying and similar reliability and validity as other questionnaires for measuring physical activity in adolescents (Jekauc et al., 2013). The reliability of assessing physical activity on the index level for one-week inter-test interval (ICC=intraclass correlation) was between $r_{ICC}=0.60$ ($p<0.01$) and $r_{ICC}=0.74$ ($p<0.01$) (Jekauc et al., 2013). Overall physical activity had an ICC of $r=0.74$ ($p<0.01$), sports club physical activity had an ICC of $r_{ICC}=0.64$ ($p<0.01$) and leisure-time physical activity had an ICC of $r_{ICC}=0.69$ ($p<0.01$). The validity (compared to Actigraph GT1M and the PDPAR – Previous Day Physical Activity Recall) was $r=0.24$ ($p<0.01$) and $r=0.43$ ($p<0.01$) for overall activity, $r=0.35$ ($p<0.01$) and $r=0.55$ ($p<0.01$) for sports club physical activity, and $r=0.10$ and $r=0.32$ ($p<0.01$) for leisure-time physical activity (Jekauc et al., 2013).

In this study, we distinguished between leisure-time activities outside sport clubs and overall PA in sports clubs because in Germany, physical activity of adolescents and young adults occurs mostly in these two settings. In addition, the two aspects were assessed using the same instrument for both age groups at both measurement points.

Overall physical activity (OPA) was assessed using a two-item questionnaire (Prochaska et al., 2001) capturing information on numbers of days during the last seven days (Item 1) and during a typical week (Item 2) of moderate physical activity of at least 60 minutes per day (not considering physical education classes). The mean of these two items combines to a scale reflecting the days per week with moderate physical activity of one hour or more according to international recommendations.

Leisure-time physical activity (LTPA) was assessed by three items: type of leisure-time physical activity, duration (minutes per session*times per week (≙ frequency) = minutes per week) of each leisure-time physical activity, and time of the year (month) of each leisure-time physical activity. These items were combined in the leisure-time physical activity index reflecting active minutes per week at leisure time:

Leisure-time physical activity index = (volume [duration*frequency]*number of months)/(12 months)

Sports club physical activity (SCPA) was assessed by four items: type of club sports activity, duration (minutes per session) and frequency (times per week) of each club sports activity, and time of the year (month) of each club sports activity. These items were combined in a club sports activity index reflecting active minutes per week at sports clubs:

Club sports index = (duration*frequency*number of month)/(12 months)

Anthropometric measures

Weight was measured with an electronic scale (SECA, Hamburg, Germany; accuracy: 0.1 kg). During the measurement the participants wore only sportswear without shoes. Height was measured by a stadiometer (SECA, Hamburg, Germany; accuracy: 0.1 cm), also without shoes.

BMI was calculated as weight divided by height squared (kg/m^2).

Sociodemographic predictors

Sex, age and socioeconomic status (SES) were included as determinants in the analysis. Two age groups were defined for each measurement point: t_0: 11 to 13 years (young) and 14 to 17 years (old); t_1: 17 to 19 years (young) and 20 to 23 years (old). Socioeconomic status was assessed by a parent questionnaire asking parental educational and professional status and total income of the family household (Lampert et al., 2002) and categorized into the three categories low, middle and high (J. Winkler & Stolzenberg, 1999).

Table 6 - Description of study sample

	N	M age (±SD)		age group (N)		SES (N)		
		t_0	t_1	young	old	low	middle	high
overall	913	14.13 ± 2.00	20.52 ± 2.06	465	448	182	477	252
boys	432	14.01 ± 21.95	20.40 ± 2.00	229	203	72	236	123
girls	481	14.23 ± 1.95	20.63 ± 2.10	236	254	110	241	129

M= mean; SD= standard deviation; SES= socio-economic status

Statistical analyses

All statistic tests were conducted using IBM SPSS 22 (IBM Corporation, Armonk, NY). The study sample was described using descriptive analyses.

The analyses of the relationship between changes in physical activity and changes in weight from baseline to wave 1 were conducted in different ways. For metrical variables (explanatory and response variable), linear regression analyses were used. Analyses of variance were conducted for categorical explanatory variables and metrical response variables.

Dealing with missing data is very important in empirical studies because missing data often lead to bias in parametric rating or to small sample sizes (Jekauc, Völkle, et al., 2012). Methods for dealing with unit-nonresponse and item-nonresponse were used to accommodate for these circumstances. Unit-nonresponse was treated by creating a weighting procedure to account for potential bias in outcome variables caused by selective unit-nonresponse (drop-out bias) (Kamtsiuris et al., 2007). In a first step, initial design weights for the baseline sample were defined using information on the probability of selection of the measurement point and the participant within the measurement point.

Subsequent data stratification ensured representativeness for the target population (German children and adolescents aged 4 to 17 years) regarding sex, age, region, migration background, and education level. Based on these initial weights, weighted logistic regressions were performed to predict the probability of participation in wave 1. In the process, baseline data on wave 1 responders and nonresponders were used to estimate differences between wave 1 responders and the baseline sample. All longitudinal participants were assigned an individual weight according to the inverse of their probability of participation (inverse probability weighting). Expected differences between wave 1 responders and nonresponders in different variables of interest were identified, and these differences were eliminated by the weighting procedure.

For item nonresponse, the Little's missing completely at random test (Little, 1988) revealed that data was missing in a systematic way (χ^2=1091, df=581, $p<0.001$) at item level among participants suggesting that deletion procedures would yield biased estimates (Schaffer & Graham, 2002). The amount of missing data due to item-nonresponse was low and ranged from 0.3% and 7.6% for all variables. Regression imputations were used to treat missing data due to item-nonresponse.

A hierarchical multiple regression model was used to quantify the association between changes in physical activity and changes in BMI values. Determinants were included successively. The difference in BMI between t_0 und t_1 was used as a criterion variable. The first model included physical activity indices in different settings (minutes) at $t_1$into the regression. In the second model, PA differences between t_0 and t_1 (delta-values) of physical activity indices in different settings were added. Sex was added in the third model. The fourth model included age and the final model considered the socio-economic status (SES).

Results

Results of the bivariate analyses (table 7)

Overall physical activity

Intraindividual differences for overall physical activity were found (T=2.58; df=912; p=0.010). The activity for at least 60 minutes of MVPA per day decreased from baseline to wave 1 on average by -0.16 days.

In addition, interindividual differences were found. Significant differences between boys and girls were found (T=-2.27; df=1.422; p=0.023; CI=0.04/0.52) between t_0 and t_1. Boys (M=-0.30 ± 2.34) showed significantly higher decrease than girls (M=-0.02 ± 2.29). No significant results were found between the three SES classes respectively between the age groups.

Leisure-time physical activity

No intraindividual differences for leisure-time physical activity were found (T=1.94; df=913; p=0.053). Physical activity outside sport clubs decreased from baseline to wave 1 on average by -8.76 minutes per week. The results were inconsistent at the interindividual level. No significant differences were found for the difference in LTPA between boys and girls, as well as between young and old age group. No significant differences between the low SES classes and middle / high classes were found in LTPA. Significant results were found for study participants of the middle SES class. Participants from the middle SES class showed a significant decrease of LTPA (T=2.71; df=1,352; p=0.007; CI=-24.66/9.10) compared to participants from the low and high SES classes. By contrast, participants from the high SES class showed an increase in LTPA (M=11.46 ± 137.37) (T=-3.05; df=887; p=0.002; CI=9.83/45.25), whereas participants from the low (M=-5.52 ± 170.86) and middle SES classes (M=-21.81 ± 186.32) showed a decrease. These differences were significant.

Sport club physical activity

Intraindividual differences for sports club physical activity were found (T=3.16; df=913; p=0.002). The physical activity in sports clubs decreased from baseline to wave 1 on average by -17.92 minutes per week.

The results at the interindividual level were inconsistent. No significant differences were found for the difference in SCPA between boys and girls. Significant results for the difference in SCPA (T=2.69; df=1,372; p=0.007; CI=-20.93/7.77) and the difference in BMI (T=8.36; df=1,416; p<0.001; CI=0.92/1.47) between t_0 and t_1 were found between the young and old age group. Both age groups showed a decrease in SCPA (old: M=-37.66 ± 134.06; young: M=-16.74 ± 150.50) and an increase in BMI values (old: M=2.34 ± 2.75; young: M=3.54 ± 2.47). All three groups of SES classes showed a decline in SCPA. Individuals from the low SES class showed the lowest significant decrease in SCPA ((M=-11.79 ± 111.96; T=-3.07; df=746; p=0.002; CI=8.48/38.69) compared to individuals from the middle and high SES classes. By contrast, participants from the high SES class showed the highest significant decrease ((M=-56.54 ± 142.61; T=-4.26; df=644; p<0.001; CI=-53.87/-19.89), followed by the middle (M=-23.63 ± 151.86) SES class.

Body mass index

Boys, the young age group and the high SES class showed significant effects on changes in BMI. Boys (M=2.30 ± 2.78) showed a lower increase than girls (M=3.37 ± 2.52), the young age group (M=3.54 ± 2.47) a higher increase than the old age group (M=2.34 ± 2.75). The smallest BMI changes were detected in the high SES class (M=2.60 ± 2.33), followed by the middle (M=2.89 ± 2.66) and low (M=2.97 ± 3.16) SES classes.

Table 7 - Mean values (±SD) of changes in difference values

		Δ BMI	**Δ_OPA (days/week)**	**Δ_LTPA (min./week)**	**Δ_SCPA (min./week)**
Overall		2.83 ± 2.71 N= 902	-0.16 ± 2.32* N= 913	-8.76 ± 170.69* N= 913	-17.92 ± 141.10* N= 886
sex	boys	2.30 ± 2.78 N= 431	-0.30 ± 2.34 N= 432	-4.33 ± 190.64 N= 432	-32.47 ± 157.88 N= 417
	girls	3.37 ± 2.52 N= 471	-0.02 ± 2.29 N= 481	-13.05 ± 148.82 N= 481	-26.47 ± 122.92 N= 469
age	young group	3.54 ± 2.47 N= 463	-0.20 ± 2.51 N= 465	-14.90 ± 163.80 N= 465	-16.74 ± 150.50 N= 448
	old group	2.34 ± 2.75 N= 439	-0.13 ± 2.18 N= 448	-4.64 ± 175.12 N= 448	-37.66 ± 134.06 N= 438
SES	low	2.97 ± 3.16 N= 180	-0.07 ± 2.13 N= 182	-5.52 ± 170.86 N= 182	-11.79 ± 111.96 N= 180
	middle	2.89 ± 2.66 N= 471	-0.39 ± 2.42 N= 477	-21.81 ± 186.32 N= 477	-23.63 ± 151.86 N= 459
	high	2.60 ± 2.33 N= 249	0.18 ± 2.26 N= 252	11.46 ± 137.37 N= 252	-56.54 ± 142.61 N= 245

OPA: overall physical activity; LTPA: leisure-time physical activity; SCPA: sport club physical activity; SES: socio-economic status BMI: body mass index
*p<0.05

Results of the hierarchical multiple regressions (table 8)

The results of the hierarchical multiple regressions were inconsistent for the different settings of physical activity.

Overall physical activity

A significant relationship between initial level of PA and BMI changes was found.

An increase of one day with at least 60 minutes of MVPA at baseline led to an increase of 0.187 BMI points. However, this effect disappeared when age and sex were added into the regression.

Adding sex and age into the regression was followed by an increase of the amount of explained variance by 3.1% for sex and 8.8% for age additionally. No changes were detected when SES was added into the regression model (model 5).

Leisure-time physical activity

Analyses of linear regressions showed no relationship between the changes in minutes of LTPA from t_0 to t_1 as well as initial level of LTPA at t_0 and changes in BMI values, independent of whether age and SES were included as determinants. Adding sex into the regression (model 3) was followed by the appearance of a significant effect of the initial level of LTPA on BMI changes. This could be caused by a suppression effect. It is assumed that sex suppressed the parts of variance in LTPA which are not related to changes in BMI. However, because of the suppression of these irrelevant variances, the relationship between LTPA and BMI changes became significant. However, this suppression effect is rather small. Adding sex and age into the regression increased the amount of explained variance by 4.0%, and by 9.2% if age was added.

Sport club physical activity

A significant relationship was found for initial level of SCPA and changes in BMI values – the higher the SCPA at the baseline, the higher the increase in BMI values from t_0 to t_1 (for each minute's increase in SCPA at baseline, the BMI increases by 0.002). Also, the differences in SCPA showed a significant relationship with changes in BMI values. In contrast, for each minute's increase of SCPA from baseline to wave 1, the BMI decreased by 0.002. Adding the difference score of SCPA into the regression increased the amount of explained variance by 0.6%. Model 3 showed that the relationship between SCPA and BMI change decreased if sex was included into the regression. Adding sex into the regression increased the amount of explained variance by 2.8%. If age was included into the regression analysis, the relationship between SCPA at t_0 and BMI changes was no longer significant. When age was added into the regression, the amount of explained variance increased by 8.4% (model 4). When SES was added into the regression, no significant changes were detected.

Table 8 - Results of the stepwise regression analyses

		model 1			**model 2**			**model 3**			**model 4**			**model 5**		
	variables	**B**[a]	**ß**[b]	**p**	**B**[a]	**ß**[b]	**p**	**B**[a]	**ß**[b]	**p**	**B**[a]	**ß**[b]	**p**	**B**	**ß**[b]	**p**
OPA (days/week)	**constante**	2.188		**<0.001**	2.**281**		**<0.001**	2.**985**		**<0.001**	9.**156**		**<0.001**	8.**911**		**<0.001**
	∑_OPA_t_0	0.187	0.126	**<0.001**	0.158	0.106	**0.002**	0.096	0.065	0.054	0.023	0.017	0.605	0.023	0.016	0.628
	Δ_OPA				0.037	0.031	0.350	0.053	0.046	0.167	0.069	0.059	0.062	0.066	0.057	0.072
	sex[d]							-0.974	-0.180	**<0.001**	-1.058	-0.195	**<0.001**	-1.100	-0.203	**<0.001**
	age_t_0[c]										-0.404	-0.299	**<0.001**	-0.399	-0.296	**<0.001**
	SES_low[e]													0.416	0.065	**0.030**
	SES_ middle[e]													0.215	0.040	0.186
	R^2	0.016			0.016			0.048			0.135			0.138		
	Adjusted R^2	0.015			0.015			0.046			0.133			0.134		
	Changes in R^2	0.016 **(p<0.001)**			0 .001 (p=0.350)			0.031 **(p<0.001)**			0.088 **(p<0.001)**			0.003 (p=0.093)		

SCPA: sport club physical activity; LTPA: leisure-time physical activity; OS index: overall sport index; OPA: overall physical activity; SES: socio-economic status BMI: body mass index

The variables were dichotomized expect where noted [d,e,f,g]

bold values represents statistically significant associations (p<0.05)

[Δ] differences between values of t_0 and t_1

[a] regression coefficient

[b] standardized regression coefficient

[c] metric data

[d] two categories

[e] three categories: dummy-coded with “high SES” as reference group

Table 8 - continued

		model 1			model 2			model 3			model 4			model 5		
	variables	**B[a]**	**ß[b]**	**p**	**B[a]**	**ß[b]**	**p**	**B[a]**	**ß[b]**	**p**	**B[a]**	**ß[b]**	**p**	**B[a]**	**ß[b]**	**p**
LTPA (min./week)	**constante**	2.857		**<0.001**	2.884		**<0.001**	3.520		**<0.001**	4.228		**<0.001**	9.184		**<0.001**
	∑_LTPA_t_0	0.000	-0.014	0.603	-0.001	-0.031	0.445	-0.002	-0.080	**0.049**	-0.001	-0.066	0.095	-0.001	-0.069	0.075
	Δ_LTPA[c]				0.000	0.023	0.559	0.001	0.065	0.109	0.001	0.048	0.223	0.001	0.047	0.221
	sex[d]							-1.098	-0.203	**<0.001**	-1.120	-0.207	**<0.001**	-1.172	-0.215	**<0.001**
	Age_t_0 [c]										-0.409	-0.303	**<0.001**	-0.404	-0.299	**<0.001**
	SES_low[e]													0.494	0.069	**0.021**
	SES_middle[e]													0.352	0.053	0.078
	R^2	0.000			0.000			0.040			0.132			0.136		
	Adjusted R^2	-0.001			-0.001			0.038			0.130			0.132		
	Changes in R^2	0.000 (p=0.603)			0.000 (p=0.576)			0.040 (p<0.001)			0.092 **(p<0.001)**			0.003 (p=0.059)		

SCPA: sport club physical activity; LTPA: leisure-time physical activity; OS index: overall sport index; OPA: overall physical activity; SES: socio-economic status BMI: body mass index

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bold values represents statistically significant associations ($p<0.05$)

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[a] regression coefficient

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[e] three categories: dummy-coded with “high SES” as reference group

Table 8 - continued

		model 1			model 2			model 3			model 4			model 5		
		B[a]	**ß[b]**	**p**	**B[a]**	**ß[b]**	**p**	**B[a]**	**ß[b]**	**p**	**B[a]**	**ß[b]**	**p**	**B[a]**	**ß[b]**	**p**
SCPA (min./week)	**constante**	2.657		**<0.001**	2.596		**<0.001**	3.154		**<0.001**	9.065		**<0.001**	8.775		**<0.001**
	∑_SCPA_t_0	0.002	.072	**0.008**	0.003	0.001	**<0.001**	0.002	0.080	**0.014**	0.001	0.039	0.209	0.001	0.048	0.132
	Δ_SCPA				-0.002	0.001	**0.004**	-0.001	-0.073	**0.023**	-0.001	-0.034	0.267	-0.001	-0.032	0.295
	sex[d]							-0.932	-0.172	**<0.001**	-1.035	-0.191	**<0.001**	-1.075	-0.198	**<0.001**
	age_t_0[c]										-0.379	-0.239	**<0.001**	-0.391	-0.288	**<0.001**
	SES_low[e]													0.456	0.072	**0.021**
	SES_middle[e]													0.199	0.037	0.231
	R^2	0.005			0.011			0.040			0.124			0.127		
	Adjusted R^2	0.004			0.010			0.037			0.121			0.123		
	Changes in R^2	0.005 **(p=0.008)**			0.006 **(p=0.004)**			0.028 **(p<0.001)**			0.084 **(p<0.001)**			0.003 (p=0.068)		

SCPA: sport club physical activity; LTPA: leisure-time physical activity; OS index: overall sport index; OPA: overall physical activity; SES: socio-economic status BMI: body mass index

The variables were dichotomized expect where noted [d,e,f,g]

bold values represents statistically significant associations (p<0.05)

[Δ] differences between values of t_0 and t_1

[a] regression coefficient

[b] standardized regression coefficient

[c] metric data

[d] two categories

[e] three categories: dummy-coded with “high SES” as reference group

Discussion

The aim of this nationwide study was to analyse the relationship between changes over a six year period in physical activity and changes in weight from adolescence into young adulthood. Overall, the results were inconsistent.

Overall physical activity

Bivariate analyses showed that the decrease in OPA was significantly higher in boys than in girls, but the increase in weight was significantly lower in boys than in girls. Unexpected results were found in the hierarchical regression analysis. The results showed that a higher level of OPA was associated with an increase of BMI values.

This effect decreased when the differences between baseline and wave 1 were added into the regression analysis. Furthermore, they disappeared completely when age was taken into the regression. These results suggest that this relationship between initial level of OPA and BMI changes was probably caused by the variable age which was a significant predictor of BMI changes. BMI decreased more with increasing age.

Comparable results were reported by Corder, van Sluijs, Ekelund, Jones, and Griffin (2010). No significant relation between BMI and MVPA time was found. However, their study revealed that body fat was a better predictor for changes in physical activity (Corder et al., 2010). In contrast, Nader, Bradley, Houts, McRitchie, and O'Brien (2008) found that in children, BMI was a significant predictor of physical activity decreases. However, these results could not be confirmed in other studies (Neumark-Sztainer et al., 2003) (Goran, Gower, Nagy, & Johnson, 1998). Also, Metcalf, Voss, Hosking, Jeffery, and Wilkin (2008) found no relationship between physical activity and changes in BMI.

After analysing more health related variables (summarised into metabolic health), however, the researchers found significant associations with physical activity guidelines (Metcalf et al., 2008). The authors declare that BMI as outcome measure is too blunt. In addition, they found that girls consistently engage in less physical activity, leading to a discussion whether the guidelines should be lowered for girls or whether girls should be given encouragement to do more (Metcalf et al., 2008).

Another aspect is related to the cut-offs of recommendations. It may be the case that more minutes of at least MVPA are necessary to achieve health enhancement. Lätt and colleagues (Latt et al., 2015) found that vigorous physical activity predicted overweight and obesity in boys. A minimum of 15 minutes per day of vigorous physical activity is desirable to reduce the risk of developing overweight or obesity.

Leisure-time physical activity

The hierarchical regression analysis only showed a significant relationship between initial level of physical activity and changes in BMI values if sex was added into the analysis. This could be caused by a suppression effect. It is assumed that sex suppressed those parts of variance in LTPA which are not related to changes in BMI. Because of the suppression of these irrelevant variances the relationship between LTPA and BMI changes became significant. However, this suppression effect is rather small and disappeared after adding age into the regression. Here, too, age affected the relationship between initial LTPA and BMI changes.

Other studies found that increased weight values are associated with decreased LTPA (de Munter, Tynelius, Magnusson, & Rasmussen, 2015; Sarma, Zaric, Campbell, & Gilliland, 2014), whereas the present study showed no relationship between LTPA and weight changes. However, these studies analysed only the differences between males and females. The effect of LTPA on BMI was much stronger in females (Sarma et al., 2014), and the different SES classes remained unconsidered. Therefore, a comparison with other studies is difficult.

In order to arrive at a more detailed interpretation, lifestyle should be considered (Dai, Wang, & Morrison, 2014). Possible reasons for changes in physical activity in different settings for girls and for boys include the limited availability of time (Tappe et al., 1989), relocation or changing personal interests during puberty. This view is supported by Gordon-Larson and colleagues who state that young adults experience a period of strong changes (Zakarian et al., 1994). Furthermore, the support for physical activity from peers and parents (Anderssen & Wold, 1992; McGuire et al., 2002; Zakarian et al., 1994) is the strongest factors for identification with physical activities (Neumark-Sztainer et al., 2003). In case of relocation, this support can disappear and evoke changes in physical activity.

Sport club physical activity

Results of the bivariate analyses showed significant differences between the young and old age group. Both age groups showed a decrease in SCPA and an increase in BMI values. It is interesting to note that with increasing age, the SCPA decreased more strongly and the BMI values increased more slowly. European studies showed a trend towards stabilization of overweight and obesity with increasing age (Crimmins et al., 2007; Peneau et al., 2009). Also, significant differences in SES classes were found. The high SES class showed the highest decrease in SCPA, but the lowest increase in BMI values. Reverse results were found in the low SES class. These results could be due to the fact that low SES class is associated with low education levels. This could lead to a deficit of knowledge above the health benefits of physical activity and the health effects from unhealthy nutrition. In addition, because of the low income the payment of (often) high membership fees is not possible and/or does not allow the purchase of high quality food. Furthermore, socially disadvantaged families are often child-rich, further complicating membership in sports clubs because of the high costs.

The analysis of hierarchical regression showed contradictory results. The higher the SCPA at the baseline, the higher the increase in BMI values from t_0 to t_1. But the higher the increase of LTPA from baseline to $t_{1,}$ the lower the BMI changes were. Regular physical activity implicates a change in body composition. Physical activity induced a change from fat mass into fat free mass. This fact can lead to unchanged or even higher BMI values. However, considering the controlled variable in the hierarchical model, it was apparent that the significant relationship disappeared if age was added. These analyses clarify that the relationship between initial SCPA and changes in BMI values are affected by age.

Because of a deficit of studies analysing leisure-time physical activity in sports club separately, a comparison with other studies is not possible.

Overall, it was apparent that the significant relationship between different indices of physical activity and changes in BMI values disappeared after adding age as a variable in the regression model. This clarified that only age caused the relationship and no direct relationship between physical activity and weight changes existed. The high importance of age for the relationship between LTPA as well as SCPA and BMI could be caused by natural changes in life.

Circumstances change during the life span – e.g. the shift from education to the job, familial changes like getting married and starting a family– and these also affect the time available for physical activity. Over time, the high and free movement time (as is typical for childhood) decreases more and more, and with each stage of life, the active lifestyle increasingly changes into an inactive lifestyle.

In addition, the significant effects of different physical activity indices had only small effect sizes, which is why it is advisable to only speak of trends.

Strength and limitations

The focus of our study was to analyse the relationship between changes in physical activity and changes in weight over a six year period. The strength of the present study ares the analyses, distinguished in different settings of physical activity. In addition, the large study sample with the large age range is a further strength of the study.

Because of the size of the sample, the study also has some limitations. Physical activity data were collected using a questionnaire that only captures subjective data. Physical activity tends to be overestimated in questionnaires, and the study sample tends to have difficulties in estimating the extent (in frequency, duration and intensity) of physical activity (Lohman et al., 2008).

Because of the higher reliability, better results could be expected if more objective methods (e.g. accelerometers for physical activity assessment and BIA for anthropometric values) were applied in studies.

Further, weight changes were analysed only with BMI. For a better assessment of changes in weight, more objective, but therefore also more extensive, measurement methods (e.g. BIA, DEXA) would be preferable. With these methods, changes in fat mass and fat free mass would become observable.

Conclusions

In this representative study, we report on the relationship between changes in physical activity and changes in weight. The results showed that the influence of physical activity in different settings on weight over a period of 6 years is not consistent and that the effect sizes were very small. These results emphasize the need for further large longitudinal studies (especially with objective methods) to improve the evidence. This would make it possible to arrive at more conclusive results. Because the results of our study showed that the relationship between changes in physical activity and changes in weight were caused by age, future interventions may need to place less on an emphasis on increasing the amount of physical activity and greater emphasis on forming a strong and early attachment to an active lifestyle. Studies such as by Telama et al. (2014) or Kjonniksen, Torsheim, and Wold (2008) have shown an association between an active lifestyle in childhood and in adulthood, and the health enhancing effects could be maintained for later in life. In addition, the difference in results, especially for SES classes and sex, highlighted the importance of detailed information on physical activity determinants in the target population before developing interventions (Bartholomew, Parcel, Kok, & Gottlieb, 2006; Corder, Ogilvie, & van Sluijs, 2009; Kahn et al., 2008).

6 General discussion

6.1 Overall summary and contentual discussion

The overall goal of the present thesis was to make a contribution to longitudinal research on development in adolescent physical activity and its association with overweight or rather body weight changes. Study I gave an overview of the state of research and revealed the existing gaps. Study II contributed towards filling one of the existing gaps: the longitudinal development of physical activity and the question of the stability of physical activity in different settings over time. Study III took up the results of Study II and analysed the relationship between changes in physical activity and changes in body weight.

Study I revealed a deficit of representative European studies analysing physical activity in more detail. In the subsequent studies, the focus was on physical activity, because of the complexity of the model and because more longitudinal changes were expected in physical activity than in physical fitness in adolescence. Study II found low tracking in physical activity from adolescent to early adulthood over a timespan of six years. Regardless of age, the influence of social economic status and sex was heterogeneous. This result showed that physical activity in different settings is not stable over time and changes from youth to adulthood. The next step considered the question of whether the effects of these changes lead to changes in body weight (Study III). Different hierarchical regression analyses showed no significant relationship between changes in physical activity indices and weight changes. Only the control variable “age” was significant.

The analyses in all three studies showed influences of age, sex and SES. Analyses of physical activity showed changes over time for both sexes. Thereby it is also explainable that the relationship between changes in physical activity and changes in weight was influenced by sex. In addition, the different studies revealed a tendency towards disadvantage in the lower socio-economic classes. This makes it clear that membership of a specific social class tends to influence the development of BMI values. Because no settings of physical activity showed obvious results in the present studies, the different results tend towards the conclusion that the settings of physical activity are not very decisive. Moreover, it is important to form a strong and early attachment to an active lifestyle. In a further step, it would be important to increase the amount of physical activity.

The overall summary showed that physical activity is a fluctuating variable that is not related to body weight changes. In addition, analyses showed a high rank-order coefficient (r=0.70) for overweight, meaning that only small weight changes were to expect. This could be a further reason why no relationship was observable. These results indicate that physical activity alone cannot stop the obesity epidemic of the 21th century. Other factors like genetics and lifestyle could play an additional role (Marti, Martinez-Gonzalez, & Martinez, 2008; Marti, Moreno-Aliaga, Hebebrand, & Martinez, 2004; Walker et al., 2015). This indicated that the analyses of particular behavioural aspects are probably insufficient and that more extensive research concepts, including research into lifestyle, are necessary to explain health. Abel (1992) explained in his illustration that a healthy lifestyle consists of three dimensions: health-related behaviour, health-related attitudes and social, cultural and economic environments. Spengler and colleagues (Spengler, Mess, Mewes, Mensink, & Woll, 2012) showed in their study (with focus on health-related behaviour) that the prevalence of overweight is outstandingly high in the cluster characterized by a low physical activity score, a low nutrition score and a high media use score. This indicates that a combination of these three lifestyle factors plays an important role in the risk of overweight (Spengler et al., 2012). Other studies also showed the importance of holistic interaction (Matheson, King, & Everett, 2012; Peirson et al., 2015).

However, this begs the question of whether overweight or weight changes can be considered to be parameters of health. Whereas overweight can contribute to various impairments of health (e.g. hypertension, diabetes type 2 or arteriosclerosis), which in turn can lead to morbidity or even mortality, body weight changes are not evaluative and have thereby no direct influence on health impairments. It would therefore be necessary to analyse overweight as well as the weight changes (positive or negative) in more detail. As mentioned in the chapter on implications, it is essential to analyse the reason for weight changes – are the weight changes caused by an increase in fat mass or by an increase in fat-free mass? Or are the subjects overweight because of high muscle density or fat density? To answer these questions, objective and technical methods are necessary. Detailed information is essential for a reliable interpretation of the relationships.

An overall comparison of the results of this study with those of other studies is difficult because this study considers the different settings of physical activity - the more specific the differentiation, the more difficult the comparison. Whereas in the field of stability coefficients the results (low to moderate rank-order correlation coefficients of different settings of physical activity) are comparable with other studies (Anderssen et al, 2005; Janz et al., 2000; Telama et al., 1996a; Telama et al, 2005), the results of the longitudinal consideration of physical activity and BMI disagreed with those of other large studies. The

Helena Study (Martinez-Gomez et al., 2010) showed, in contrast to the present study, that overall physical activity (physical activity guidelines) was effective in preventing high body fat. Comparable results were found by Janz, KF., Golden, JC., Hansen, JR. and Mahoney, LT. (1992) in the Muscatine Study. Janz and colleagues (1992) found that body fat was inversely related to physical activity. However, a final conclusion is difficult because of the differences in the measurement methods. Physical activity and body composition were measured using different objective and subjective measurement methods.

6.2 Methodological discussion

The present dissertation makes a contribution towards closing the deficit in European longitudinal studies concerning the development of and relationship between physical activity and weight. But further research is still necessary. Physical activity was measured in different settings (leisure-time physical activity outside sports clubs; leisure-time physical activity in sports clubs; overall physical activity). Data on the intensity, frequency, duration and type of each physical activity was gathered. Moreover, the large study populations and the resulting representativeness are further strengths of the studies. But the large number of study participants also entailed some limitations in the measurement methods. Physical activity was measured by the MoMo-PAQ. Research based on physical activity questionnaires tend towards falsified results because of social desirability (Steenkamp, de Jong, & Baumgartner, 2010), recall bias and over- or underestimation (Lohman et al., 2008). Overall, questionnaires showed lower reliability than objective methods like accelerometers (Jekauc et al., 2013). The capture of body composition data in the form of the body mass index is also a consequence of the large sample size. Evaluation of changes in body weight is difficult if no further information about fat mass and fat-free mass is available. Technically sophisticated methods were desirable and necessary for more detailed statements on the evaluation of weight changes. These are possible reasons for results of the present study.

As well as the content-related limitations, there are also methodological limitations. One methodological limitation is that body weight was considered as a health outcome variable. Body weight, respectively overweight, is not an ideal parameter of health. Information based on more expressive data (e.g. fat mass) would be a better parameter of health. Furthermore, dropouts in during the longitudinal research period pose a considerable problem. For this reason, a weighting factor was developed to eliminate bias in parametric rating or resulting from a small sample size (Jekauc et al., 2012). But this could lead to distortions, also because of the estimated values for the missing data. This could be a possible reason for the small tracking coefficients and for the apparent non-existence of relationships.

Referring to Figure 2, these results have an influence on guidance (Step 4) and the development of interventions (Step 5). Further implications are described in the following chapter.

6.3 Implications

The results and the limitations revealed some **implications for future research** (referring to Step 4 in Figure 2).

- The use of objective and more reliable measurement methods is necessary
- Despite the fact that the present “simple” analyses showed no significant results, the analyses should be more complex – adding more factors into the analyses:

  Studies analysing only physical activity as an independent variable will not suffice. Based on the model of Bouchard et al. (2007; Bouchard et al., 2012) other factors, like lifestyle behaviour (media use or sedentariness in general, eating behaviour) and social as well as environment conditions should be included. If possible, also the attitude towards health is important and should be included into further analyses (Abel, 1992). Referring to Spengler (2014), multiple approaches toward health behaviours showed meaningful and stronger relationships with health than the single consideration of physical activity.
- Consideration of physical fitness variables:

  Analyses of physical fitness parameters as mediator or moderator
- Consideration of the energy expenditure of different physical activities
- If future research shows that relationships exist, in view of the stated implications, the direction of the relationship should be analysed. This would reveal new implications for the design of interventions.

The founded results of the present dissertation do not allow some implications for interventions (step 5, Figure 2).

7 General conclusion

Based on the model of Bouchard et al. (2007; 2012) health is a complex construct dependent on numerous factors. As well as genetics and physical activity, health-related fitness and other factors influence health outcome parameters. One outcome variable of health is overweight, because it can have a negative impact on health status. Because of the long-term worsening of youth health status, the topic is now of increased and lasting importance in national and international research. The demand for evidence is increasing more and more and the causes of health impairment are multifactorial. The present thesis expands the existing research on adolescent physical activity and its relationship with adolescent health, its results confirming that physical activity alone cannot influence health.

Overall, the results of these different studies did not confirm the assumptions in the model of Bouchard et al. (2006; 2012) and Hallal et al. (2006) which assumed that physical activity is directly related to health, in cross-sectional as well as in longitudinal studies. But the results do emphasize the influence of other factors on health. Some implications for further research should therefore be mentioned: lifestyle factors like media use, eating behaviour and aspects of the social, cultural and economic environment should be integrated into the analyses. Furthermore, referring to the model presented here, physical activity should be analysed in combination with health-related fitness.

8 Record of achievement

The author of this dissertation, Annette Henn, made the following contributions to the dissertation project:

She is responsible for the overall conception and design of the dissertation concept and the dissertation thesis. From 01/2011 to today, she worked in the research group conducting the "Motorik-Modul" Study.

In Studies I, II and III Annette Henn was responsible for the overall conception and design of the manuscripts, performed the statistical analyses, interpreted the data and drafted the manuscript.

Furthermore, she was responsible for the submission and the revision process of the journal articles.

Studies II and III were developed within the MoMo Longitudinal Study (2009 – 2021): Physical fitness and physical activity as determinants of health development in children and adolescents. The MoMo Longitudinal Study (funding reference number: 01ER1503) is funded by the German Federal Ministry of Education and Research as part of the long-term studies public health research program.

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