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# **Physical fitness in school-aged children**

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**Table of content**

Abstract .....	iii
Zusammenfassung .....	vi
List of figures.....	ix
List of tables .....	x
Abbreviations.....	xi
<b>1. General introduction .....</b>	<b>1</b>
<b>2. Explanation of terms .....</b>	<b>5</b>
2.1 School-aged children .....	5
2.2 Theoretical concept of physical fitness.....	6
2.2.1 Health-related physical fitness.....	8
2.2.2 Performance-related fitness .....	10
<b>3. Literature review .....</b>	<b>11</b>
3.1 Development of physical fitness.....	11
3.2 Modifying factors' association to physical fitness .....	16
3.2.1 Living area .....	16
3.2.2 Sports club participation .....	21
3.2.3 Socioeconomic status (SES) .....	23
3.3 Physical fitness and health.....	27
3.3.1 Benefit of physical fitness on health .....	27
3.3.2 Tracking of physical fitness .....	37
<b>4. Research objectives.....</b>	<b>39</b>
<b>5. Methods.....</b>	<b>42</b>
5.1 Study design & Participants.....	42
5.2 Physical fitness testing.....	45
5.2.1 Study 1 & Study 2.....	45
5.2.2 Study 3 .....	48
5.2.3 Quality criteria of conducted physical fitness tests.....	49
5.3 Assessment of modifying factors on physical fitness .....	53
5.3.1 Anthropometry .....	53
5.3.2 Living area .....	53
5.3.3 sports club participation & organized sports participation .....	53
5.3.4 Socioeconomic status.....	54
<b>6. Studies.....</b>	<b>55</b>
6.1 Study 1 – Physical fitness percentiles.....	55
6.1.1 Abstract.....	56

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6.1.2	Introduction.....	57
6.1.3	Methods.....	58
6.1.4	Results.....	62
6.1.5	Discussion.....	68
6.1.6	Conclusion.....	71
6.1.7	References.....	72
6.2	Study 2 – Effect of living area & sports club participation on PF.....	75
6.2.1	Abstract.....	76
6.2.2	Introduction.....	77
6.2.3	Methods.....	79
6.2.4	Results.....	81
6.2.5	Discussion.....	86
6.2.6	Conclusion.....	88
6.2.7	References.....	89
6.3	Study 3 – Socioeconomic differences in PF.....	92
6.3.1	Abstract.....	93
6.3.2	Introduction.....	94
6.3.3	Methods.....	95
6.3.4	Results.....	99
6.3.5	Discussion.....	102
6.3.6	Conclusion.....	105
6.3.7	References.....	105
<b>7.</b>	<b>General discussion.....</b>	<b>107</b>
7.1	Development of PF.....	107
7.2	Effect of living area on physical fitness development.....	109
7.3	Effect of sports club participation on physical fitness development.....	120
7.4	Role of socioeconomic status on physical fitness.....	125
<b>8.</b>	<b>Conclusion.....</b>	<b>131</b>
<b>9.</b>	<b>References.....</b>	<b>132</b>
	Authors’ contribution.....	ix
	Curriculum vitae.....	x
	Danksagung (Acknowledgement).....	xi

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## Abstract

### *Background*

Physical fitness is an important marker of health that enables people to carry out activities of daily living with vigour and alertness but without undue fatigue and with sufficient reserve to enjoy active leisure pursuits and to meet unforeseen emergencies. Especially, due to scientific findings that the onset of civilization diseases (e.g., obesity, cardiovascular disease) begins in childhood and that physical fitness tracks (at least) into young adulthood, the regular monitoring and promotion of physical fitness in children is risen up to a public health issue. In relation to the evaluation of a child's physical fitness over time (i.e., development) the use of longitudinally-based percentile values is of particular interest due to their underlined dedication of true physical fitness development within subjects (i.e., individual changes in timing and tempo of growth and maturation). Besides its genetic determination (e.g., sex, body height), physical fitness is influenced by factors that refer to children's environment and behaviour. For instance, disparities in physical fitness according to children's living area are frequently reported concerning the fact that living in rural areas as compared to urban areas seems to be more favourable for children's physical fitness. In addition, cross-sectional studies found higher fitness values in children participating in sports clubs as compared to non-participants. However, up to date, the observed associations between both (i.e., living area and sports club participating) and children's physical fitness are unresolved concerning a long-term effect. In addition, social inequality as determined by the socioeconomic status (SES) extends through many areas of children's life. While evidence indicates that the SES is inversely related to various indices of child's daily life and behaviour like educational success, nutritional habits, and sedentary- and physical activity behaviour, a potential relationship between child's physical fitness and the SES is hardly investigated and indicated inconsistent results.

The present thesis addressed three objectives: (1) to generate physical fitness percentiles for 9- to 12- year-old boys and girls using a longitudinal approach and to analyse the age- and sex-specific development of physical fitness, (2) to investigate the long-term effect of living area and sports club participation on physical fitness in third- to sixth-grade primary school students, and (3) to examine associations between the SES and physical fitness in a large and representative (i.e., for a German federal state) sample of third grade primary school students.

### *Methods*

(i/ii) Healthy third graders were followed over four consecutive years (up to grade 6), including annually assessment of physical fitness and parental questionnaire (i.e., status of sports club participation and living area). Six tests were conducted to estimate various components of physical fitness: speed (50-m sprint test), upper body muscular power (1-kg ball push test), lower body muscular power (triple hop test), flexibility (stand-and-reach test), agility (star agility run test), and cardiorespiratory fitness (CRF) (9-min run test). (iii) Within a cross-sectional study (i.e., third objective), physical fitness of third graders was assessed by six physical fitness tests including: speed (20-m sprint test), upper body

muscular power (1-kg ball push test), lower body muscular power (standing long jump [SLJ] test), flexibility (stand-and-reach test), agility (star agility run test), and CRF (6-min run test). By means of questionnaire, students reported their status of organized sports participation (OSP).

### *Results*

(i) With respect to percentiles of physical fitness development, test performances increased in boys and girls from age 9 to 12, except for males' flexibility (i.e., stable performance over time). Girls revealed significantly better performance in flexibility, whereas boys scored significantly higher in the remaining physical fitness tests. In girls as compared to boys, physical fitness development was slightly faster for upper body muscular power but substantially faster for flexibility. Generated physical fitness percentile curves indicated a timed and capacity-specific physical fitness development (curvilinear) for upper body muscular power, agility, and CRF. (ii) Concerning the effect of living area and sports club participation on physical fitness development, children living in urban areas showed a significantly faster performance development in physical fitness components of upper and lower body muscular power as compared to peers from rural areas. The same direction was noted as a trend in CRF. Additionally, children that regularly participated in a sports club, when compared to those that not continuously participated in a sports club demonstrated a significantly faster performance development in lower body muscular power. A trend of faster performance development in sports club participants occurred in CRF too. (iii) Regarding the association of SES with physical fitness, the percentage of third graders that achieved a high physical fitness level in lower body muscular power and CRF was significantly higher in students attending schools in communities with high SES as compared to middle and low SES, irrespective of sex. Similar, students from the high SES-group performed significantly better in lower body muscular power and CRF than students from the middle and/or the low SES-group.

### *Conclusion*

(i) The generated percentile values provide an objective tool to estimate children's physical fitness within the frame of physical education (e.g., age- and sex-specific grading of motor performance) and further to detect children with specific fitness characteristics (low fit or high fit) that may be indicative for the necessity of preventive health promotion or long term athlete development. (ii) It is essential to consider variables of different domains (e.g., environment and behavior) in order to improve knowledge of potential factors which influence physical fitness during childhood. In this regard, the present thesis provide a first input to clarify the causality of living area and sports club participation on physical fitness development in school-aged children. Living in urban areas as well as a regular participation in sports clubs positively affected children's physical fitness development (i.e., muscular power and CRF). Herein, sports club participation seems to be a key factor within the relationship between living area and physical fitness. (iii) The findings of the present thesis imply that attending schools in communities with high SES refers to better performance in specific physical fitness test items (i.e., muscular power, CRF) in third graders. Extra-curricular physical education classes may represent an important equalizing



factor for physical activity opportunities in children of different SES backgrounds. In regard to strong evidence of a positive relationship between physical fitness - in particular muscular fitness/ CRF - and health, more emphasis should be laid on establishing sports clubs and extra-curricular physical education classes as an easy and attractive means to promote fitness-, and hence health- enhancing daily physical activity for all children (i.e. public health approach).

*Keywords:* physical fitness, school-aged children, living area, sports club participation, socioeconomic status

## Zusammenfassung

### *Hintergrund*

Die motorische Leistungsfähigkeit (LF) ist eine bedeutsame Determinante eines ganzheitlich ausgerichteten Verständnisses von Gesundheit. Sie ermöglicht es dem Individuum Alltagsaktivitäten mit Kraft und Aufmerksamkeit durchzuführen, ohne übermäßige Ermüdung und mit genügend Reserven, um Freizeitaktivitäten nachzugehen und belastende und unvorhersehbare Situationen zu meistern. Verbunden mit der Evidenz, dass ein Großteil der heutigen Zivilisationskrankheiten (z. B. Adipositas, Herz-Kreislaufkrankungen) ihren Ursprung in der Kindheit haben und das relative Niveau der motorischen LF (zumindest) bis in das junge Erwachsenenalter hin stabil ist, etabliert sich die kontinuierliche Erfassung und Förderung motorischer Fitness im Kindesalter zu einem primären volkswirtschaftlichen Gesundheitsziel. In Verbindung mit der Erfassung der motorischen LF von Kindern über die Zeit (d. h. Entwicklung) ist der Nutzen Längsschnitt basierter Perzentilwerte aufgrund der Detektion von individuellen Leistungsentwicklungen (d. h. zeit- und frequenzspezifische Variationen in Wachstum und Reifung) von Relevanz. Neben der genetischen Determination (z. B. Geschlecht, Körperhöhe), wird die motorische LF auch durch Verhaltens- und Umweltfaktoren beeinflusst. Unterschiede in der motorischen LF in Abhängigkeit von der Wohngegend wurden häufig diskutiert. Es scheint, dass das Aufwachsen in der Stadt, im Vergleich zu auf dem Land, für die motorische LF von Vorteil ist. Des Weiteren weisen Querschnittsstudien auf eine bessere motorische Leistung von Sportvereinsmitgliedern im Vergleich zu Nicht-Mitgliedern hin. Die gefundenen Zusammenhänge beider Faktoren (d. h. Wohngegend und Sportvereinsmitgliedschaft) mit der motorischen LF wurden bisher aber noch nicht hinsichtlich eines Ursache-Wirkungs-Verhältnisses untersucht. Soziale Ungleichheit, u. a. determiniert über den sozioökonomischen Status (SES), findet sich in vielen Lebensbereichen von Kindern wieder. Während gut belegt ist, dass der SES negativ mit Lebens- und Verhaltensindikatoren wie Bildungserfolg, Ernährungsgewohnheiten und Bewegungsverhalten korreliert, ist ein Zusammenhang mit der infantilen motorischen LF kaum untersucht und wenn, mit inkonsistenten Ergebnissen.

Mit Bezug auf die Kohorte “Grundschüler/innen” widmet sich die vorliegende Arbeit der Realisierung von drei Zielstellungen: (i) Der Erstellung von alters- und geschlechtsspezifischen Perzentilen (d. h. Normwerte) zur Entwicklung der motorischen LF (d. h. Normwerte) und inbegriffenen Analysen zum Einfluss von Alter und Geschlecht. (ii) Der Klärung eines möglichen Einflusses von Wohnort und Sportvereinsmitgliedschaft auf die motorische LF. (iii) Der Klärung eines möglichen Zusammenhanges zwischen dem SES und der motorischen LF.

### *Methodik*

(i/ii) Im Längsschnitt-Design wurden Schülerinnen und Schüler (SuS) der dritten Jahrgangsstufe (JST) einmal jährlich über vier Jahre hinweg (d. h. bis JST 6) in ihren motorischen Leistungen getestet. Die motorische Leistungserfassung beinhaltete sechs Testaufgaben: Schnelligkeit (50-m Sprint), Schnellkraft der oberen Extremität ([o. Extr.],

Vollballstoß), Schnellkraft der unteren Extremität ([u. Extr.], Dreier Hopp), Beweglichkeit (Rumpfbeuge), Koordination unter Zeitdruck ([Koordination], Sternlauf) und Ausdauer (9-min Lauf). Mittels elterlichem Fragebogen wurde die Mitgliedschaft in einem Sportverein (ja/nein) sowie der Wohnort (Stadt/Land) der SuS erfasst.

(iii) Im Rahmen einer Querschnittsstudie absolvierten SuS der JST 3 sechs motorische Testaufgaben: Schnelligkeit (20-m Sprint), Schnellkraft der o. Extr. (Medizinballstoß), Schnellkraft der u. Extr. (Standweitsprung), Beweglichkeit (Rumpfbeuge), Koordination (Sternlauf) und Ausdauer. Zusätzlich wurden die SuS zur Aktivität im organisierten Sport befragt (Sportverein und/oder Schulsportarbeitsgemeinschaft [Sport-AG]: ja/nein).

### *Ergebnisse*

(i) Die motorische LF der initial 9-jährigen Jungen und Mädchen (JST 3) steigerte sich bis zum 12. Lebensjahr (JST 6). In der Beweglichkeit wiesen die Testleistungen der Jungen keine Leistungsentwicklung aus (d. h. konstante Leistung). In allen Jahren erzielten Mädchen bessere Leistungen in der Beweglichkeit, wohingegen die Jungen in den übrigen motorischen Leistungsbereichen besser abschnitten. Mit Blick auf die Entwicklung der motorischen LF über die Zeit zeigte sich eine marginal schnellere Leistungsentwicklung der Mädchen im Vergleich zu den Jungen in der Schnellkraft (o. Extr.) und der Koordination sowie eine deutliche schnellere Leistungsentwicklung in der Beweglichkeit. Die erstellten Perzentilkurven detektierten eine zeit- und fähigkeits-, nicht aber geschlechtsspezifische Entwicklung der motorischen LF (kurvenförmige Leistungsentwicklung in der Schnellkraft der o. Extr., Koordination und Ausdauer). (ii) Im zeitlichen Verlauf steigerte sich die motor. LF von SuS, die in der Stadt lebten gegenüber SuS aus ländlichen Regionen schneller (d. h., Schnellkraft der o. und u. Extr., tendenziell: Ausdauer). Immer-Sportveinsmitglieder zeigten gegenüber Nie-Mitgliedern eine schnellere Entwicklung in ihrer motor. LF (d. h. Schnellkraft u. Extr., tendenziell: Ausdauer). (iii) Der Anteil an SuS, die ein hohes motorisches Leistungslevel erreichten (d. h. Schnellkraft u. Extr., Ausdauer) war höher in der Gruppe mit hohem SES im Vergleich zur Gruppe mit mittlerem und niedrigem SES. Similar, students from the high SES-group performed significantly better in lower body muscular power and CRF than students from the middle and/or the low SES-group.

### *Schlussfolgerung*

(i) Die erstellten Perzentile/Normwerte bieten ein Instrument zur objektiven Bewertung der motorischen LF und ihrer Entwicklung im Sportunterricht (d. h. alters- und geschlechtsspezifische Benotung der motorischen Leistung). Darüber können SuS mit spezifischen Leistungsausprägungen (z. B. geringe/hohe motorische Leistung) identifiziert werden und somit eine erste Indikation zur Bewegungsförderung oder einem langfristigen Leistungsaufbau im Sport gegeben werden.

(ii) Im Zusammenhang mit einem verbesserten Kenntnisstand zu potentiellen Einflussfaktoren auf die infantile motorische LF, ist es bedeutsam Variablen verschiedener Lebensbereiche in wissenschaftlichen Studien zur motor. LF zu berücksichtigen. Daran anknüpfend präsentiert die vorliegende Arbeit erste Erkenntnisse zum Einfluss von Wohngegend und Sportvereinsmitgliedschaft auf die Entwicklung der motorischen LF im

Schulkindalter. Das Aufwachsen in der Stadt sowie eine kontinuierliche Mitgliedschaft im Sportverein haben einen positiven Einfluss auf die Entwicklung motorischer Leistungen (d. h. Schnellkraft und Ausdauer). Die Mitgliedschaft im Sportverein scheint eine positive Schlüsselrolle (d. h. Mediator) in der Beziehung zwischen Wohngegend und motorischer LF einzunehmen.

(iii) Kinder, die Schulen in Gemeinden mit hohem SES besuchten erzielten bessere motorische Leistungen (d. h. Schnellkraft und Ausdauer). Mit Blick auf die deutlichen Hinweise eines positiven Zusammenhangs zwischen der motorischen LF – insbesondere Ausdauer- und Kraft determinierte Komponente – und der Gesundheit, sollte ein größerer Schwerpunkt auf die Gründung/Einrichtung von Sportvereinen und Sport-AGs gelegt werden als ein attraktives und ungezwungenes Setting zur Förderung gesundheitswirksamer körperlicher Aktivität für alle Kinder.

*Schlüsselwörter:* motorische Leistungsfähigkeit, Grundschüler/innen, Wohngegend, Sportvereinsmitgliedschaft, sozioökonomischer Status

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**List of figures**

<b>Figure 1:</b>	Flow chart of the sampling procedure of study 1 and study 2.....	43
<b>Figure 2:</b>	Measurement of physical fitness in the studies of the present thesis.....	45
<b>Figure 3:</b>	Schematic description of the ball push test (kneeing). (a: starting position, b: counter-rotation of the trunk. c: push action).....	46
<b>Figure 4:</b>	Schematic description of the triple hop test.....	47
<b>Figure 5:</b>	Schematic description of the stand-and-reach test (a: starting position, b: ending position). .....	47
<b>Figure 6:</b>	Schematic description of the ball push test (standing position). (a: starting position, b: countermovement of the trunk, c: push action). .....	49
<b>Figure 7:</b>	Schematic description of the standing long jump. ....	49
<b>Figure 8:</b>	Schematic description of the ball push test (1: starting position, 2: push action). .....	59
<b>Figure 9:</b>	Schematic description of the star agility run test. ....	61
<b>Figure 10:</b>	Smoothed LMS curves for the 10 <sup>th</sup> , 50 <sup>th</sup> , and 90 <sup>th</sup> percentiles of the (a) 50-m sprint test, (b) ball push test, (c) triple hop test, (d) stand-and-reach test, (e) star agility run test, and (f) 6-min run test in boys and girls from age 9 to 12 years. ....	67
<b>Figure 11:</b>	Development of physical fitness in primary school children according to grade and living area: (a) 50-m sprint, (b) 1-kg ball push, (c) triple hop, (d) stand-and-reach, (e) star coordination run, and (f) 9-min run. Notes. * $p < 0.05$ ; † $p < 0.01$ ; Filled triangles indicate urban and unfilled triangles indicate rural children. ....	82
<b>Figure 12:</b>	Development of physical fitness in primary school children according to class and sports club participation: (a) 50-m sprint, (b) 1-kg ball push, (c) triple hop, (d) stand-and-reach, (e) star coordination run, and (f) 9-min run. Notes. * $p < 0.05$ ; † $p < 0.01$ ; ‡ $p < 0.001$ ; Filled circles indicate children with and unfilled circles indicate children without continuous sports club participation. ....	83
<b>Figure 12:</b>	Schematic description of the star agility run test. ....	98
<b>Figure 13:</b>	Physical fitness differences in 12,460 primary school-aged children (male: $n = 6,289$ ; female: $n = 6,171$ ) by socioeconomic status (low: $n = 2,699$ ; middle: $n = 5,260$ ; high: $n = 4,501$ ). (a) 20-m sprint test, (b) ball push test, (c) standing long jump test, (d) stand-and-reach test, (e) star agility run test, and (f) 6-min run test. Notes. <i>P</i> -values of the adjusted ANCOVA (covariates: age, organized sports participation) for comparison of physical fitness between categories of socioeconomic status.....	102

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**List of tables**

<b>Table 1:</b>	Definition of the main physical fitness components.....	7
<b>Table 2:</b>	Components of physical fitness and specification of health-related physical fitness.....	8
<b>Table 3:</b>	Study comparison by urban – rural differences in physical fitness of school-aged children <sup>[1]</sup> .....	18
<b>Table 4:</b>	Reported values of reliability and validity for the physical fitness tests included in the present thesis. ....	51
<b>Table 5:</b>	Development of anthropometry and physical fitness in 9 to 12 years old boys (n = 152) and girls (n = 88). ....	63
<b>Table 6:</b>	Smoothed age- and sex-specific percentile values for the 50-m sprint (s), ball push test (m), and triple hop test (m). ....	65
<b>Table 7:</b>	Smoothed age- and sex-specific percentile values for the stand-and-reach test (cm), star agility run (s), and the 9-min run test (m). ....	66
<b>Table 8:</b>	Description of all physical fitness test items (Bös 2001, 2009, Stark 2001) and the respective motor ability (in parentheses). ....	80
<b>Table 9:</b>	Description of the study sample (103 boys, 69 girls) by class and sex. ....	84
<b>Table 10:</b>	Results of the ANOVA (adjusted for sex) with repeated measures on class by living area.....	85
<b>Table 11:</b>	Results of the ANOVA (adjusted for sex and living area) with repeated measures on class by sports club participation. ....	85
<b>Table 12:</b>	Characteristics of the study participants by physical fitness level and sex. ....	95
<b>Table 13:</b>	Relative frequencies (%) in categories of socioeconomic status (SES) according to physical fitness level (low-fit: $\leq 25^{\text{th}}$ percentile; high-fit: $>75^{\text{th}}$ percentile) for males ( $n = 6,289$ ) and females ( $n = 6,171$ ), separately. Frequencies illustrate the number of subjects in each SES group who achieved a low or a high physical fitness level.....	100
<b>Table 15:</b>	Living area comparison: characteristic of studies <sup>[1]</sup> according to geographic area, development and economy status, living area classification, anthropometry characteristics, and physical fitness. .	114

**Abbreviations**

BAH	bent arm hang
BF	percentage of body fat
BMC	bone mineral content
BMD	bone mineral density
CoP	center of pressure
CRF	cardiorespiratory fitness
CVD	cardiovascular disease
CU	curl ups
HGS	hand grip strength
IOM	Institute of Medicine
MC	motor quotient
MF	muscular fitness
MVPA	moderate to vigorous physical activity
PA	physical activity
PF	physical fitness
PU	push ups
SES	socioeconomic status
SSF	skinfold thickness
SLJ	standing long jump
SR	sit and reach
SU	sit ups
VJ	vertical jump
VO <sub>2</sub> max	maximum oxygen uptake
WC	waist circumference
WHR	waist-to-hip-ratio
20-m-SRT	20-meter shuttle run test





## 1. General introduction

Physical fitness is characterized by people's ability to carry out daily activities with vigour and alertness but without undue fatigue and with sufficient reserve to enjoy active leisure pursuits and to meet unforeseen emergencies (Caspersen et al. 1985, IOM, 2012). Furthermore, physical fitness can be understood as an integrated measurement of all the functions - cardiorespiratory, musculoskeletal, endocrine-metabolic, psychological - and structures involved in the performance of daily physical activity as well as sports-related physical exercise (Castillo-Garzón et al. 2006).

In relation to the intensive research efforts to combat the public health burden of civilization diseases such as obesity, depression and cardiovascular disease, physical fitness of children was recently highlighted as a key factor of individual's lifelong health. More specifically, a large amount of studies underline the crucial role of sufficient levels of cardiorespiratory, musculoskeletal, and motor fitness (e.g., balance, coordination) on children's physical, mental, cognitive, and social capability (Haapala 2013, Morales et al. 2013, Ortega et al. 2008, Smith et al. 2014, Steele et al. 2008). Additionally, longitudinal analysis from childhood over adolescence into young adulthood revealed both that children's physical fitness tracks into young adulthood and that the physical fitness status predicts health outcomes over this time frame (Hruby et al. 2012, Kristensen et al. 2006, J R Ruiz et al. 2009, Twisk et al. 2000). Beside the positive impact of physical fitness on health, there has been public concern about youth physical fitness status, particularly since the new millennium. A bulk of studies resumed that the physical fitness of children decreased within the last decades and that differences between the fit and the unfit children increased further (Albon et al. 2010, Runhaar et al. 2010, Sandercock, Voss et al. 2010, Tomkinson & Olds 2007, Wedderkopp et al. 2004).

While physical fitness testing has always been a proven method in the sports specific process of talent identification, the mentioned evidence of physical fitness' relation to health as well as its unfavourable secular changes has globally led to scientific and political recommendations for a regular screening of physical fitness and treatment of inadequate fitness in childhood on a population level (DOSB 2013, Fulton et al. 2004, IOM 2012, KMK 2010, Santos & Mota 2011). In conjunction to these recommendations, the evaluation of child's physical fitness is becoming more and more an inherent part of physical education curriculum in schools since all children, irrespective of their ethical and socioeconomic background can be reached (Aires et al., 2010, Pelegrini et al. 2011, Tambalis et al. 2011). Especially in the school setting, the testing of physical fitness - as practical and fundamental part of the evaluation process - is inevitable conducted by the use of field-based tests. Compared to more sophisticated laboratory-based test equipment (e.g., cycle ergometer, force plate), these tests are an operational and recognized alternative since they are time-efficient, low in cost and equipment requirements and can be easily administered to a large number of persons simultaneously. (E. G. Artero et al. 2011,

Castro-Piñero et al. 2010). Of note, the evaluation of physical fitness requires the presence of actual and valid norm values (regarding the applied fitness tests), mostly provided by percentile values. Percentile values are of interest to estimate the proportion of children with low or high physical fitness and hence, to identify the target population for primary prevention as well as for talent promotion in a sports club. In recent years, a large number of cross-sectional studies reported physical fitness percentiles for a wide variety of physical fitness tests in children (Bös, Schlenker et al. 2009, Castro-Piñero et al., 2009, Catley & Tomkinson, 2013, De Miguel-Etayo et al. 2014, Roriz De Oliveira et al. 2014). However, with regard to an evaluation of a child's physical fitness over time (i.e., development) the use of longitudinally-based percentile values is of particular interest due to their underlined dedication of true physical fitness development within subjects (i.e., individual changes in timing and tempo of growth and maturation).

Physical fitness is in part genetically determined (Bouchard et al. 1997, Bray et al. 2009) (e.g., sex, distribution of muscle fibers types), but it can also be immensely influenced by lifestyle factors. These factors can be crucial in enhancing and maintaining physical fitness during childhood. Thus, knowledge about their impact on physical fitness in children ought to be of significant interest for coaches, teachers and politicians that are entrusted with fostering children's physical fitness.

With respect to environmental living conditions, literature clearly revealed an association between children's physical fitness and their area of residence (Chillón et al. 2011, Lovecchio et al. 2015, J. H. Wang et al. 2013). Specifically, most of the studies researching the topic during the last 15 years resumed better physical fitness in children living in rural compared to urban areas. For example, within the scope of a nationwide survey of 8- to 9-year-olds' Greek rural residents outperformed their urban peers in proxies of cardiorespiratory fitness (CRF) (20-m shuttle run [20-m SRT]), muscular power of the upper (1-kg ball push) and lower body (vertical jump), and speed (30-m sprint) (Tambalis et al. 2011). Particularly, in tests of CRF (i.e., 1-mile run, 20-m SRT) a performance gain of rural living children aged 9 to 12 from different nations (e.g., Australia, India, Switzerland, Iceland) is highlighted (Adamo et al., 2011, Dollman & Norton 2002, Karkera et al. 2013, Kriemler et al. 2008, Magnusson et al. 2008). In contrast, according to recently published research, there are further hints of a better physical fitness of urban residents during the transition from childhood to adolescents (i.e.,  $\geq 11$  years) when compared to their rural counterparts (Andrade et al. 2014, Lovecchio et al. 2015, Sandercock et al. 2011). Even though the published cross-sectional research primarily stated relations between physical fitness and living area, longitudinal examinations of a cause-and-effect relationship that can answer the question if living area is a notable determinant of children's physical fitness development, are missing.

As a primary context for regular physical activity and exercise, participating in a sports club is pointed out to be highly beneficial for children's physical fitness. Relatively few studies investigated the relationship between physical fitness and sports club participation and confirm that children participating in a sports club are physically fitter than their non-participating peers (Ara et al. 2004, Ara et al. 2006, Drenowatz et al. 2013,

Vandorpe et al. 2012, Zahner et al. 2009). For instance, German second graders (6-8 years) who participated in a sports club at least once a week performed significantly better in measures of CRF (6-min run), muscular power of the upper body (medicine-ball throw), coordination (throw-and turn), and balance (one-leg stance) when compared to their non-participating peers (Drenowatz et al. 2013). Similarly, in a sample of first- (6-7 years) and fifth-grade (10-12 years) students from Switzerland, members of a sports club achieved significantly higher values for the fitness components coordination (sum z-score of balancing backwards and throw-on-target), CRF (20-m SRT), and strength (sum z-score of 1-kg ball push, jump-and-reach, sit-ups [SU], and bent-arm-hang) (Zahner et al. 2009). Therefore, it can be argued that physically fit children are more attracted to participate in a sports club (e.g., due to interest in sports activities and a higher likelihood of success) and hence this selection bias might account for the positive association between physical fitness and sports club participation observed. Owing to a lack of longitudinal research, up to now it is unresolved if regular participation in a sports club positively influences physical fitness development in children and thus comes up to public's beneficial expectations.

Furthermore, evidence indicates that the socioeconomic status (SES) is related to children's health. For instance, children living under conditions of limited economic and social capital (i.e., low SES), especially in industrialized nations, are faced with more unfavourable appearances of diet, sedentary behaviour activities, adiposity/overweight, physical activity, and cardiovascular disease risk factors (Batty & Leon 2002, Borraccino et al. 2009, Fairclough et al., 2009, Kleiser et al. 2009, Van Lenthe et al. 2001). However, at this time only limited information is available regarding a potential (positive) association between SES and physical fitness in children. In addition, the few published studies are methodologically flawed due to the fact of only testing for CRF, including relatively small samples, and/or revealed inconsistent findings (e.g., more SES-specific differences in girls, variation by fitness components) (Bös, Worth et al. 2009, Freitas et al. 2007, Kristensen et al. 2006, Van Lenthe et al. 2001, Vandendriessche et al. 2012). For example, it was observed in 6 to 11 year old Flemish students that girls with a high SES (related to parental occupation) outperformed their low SES peers in measures of CRF (20-m SRT), speed/agility (10 x 5-m shuttle run), abdominal muscular endurance (SU), flexibility (shoulder), and coordination (summed score of 4 items) but no SES-related fitness differences were observed in muscular fitness (e. g. hand grip, standing long jump, SU). In male peers, only performance differences by SES were present for muscular endurance (SU) and coordination in favour of high SES (Vandendriessche et al. 2012). Taking into account the reported increase of socioeconomic inequalities in industrialized nations, particularly in Germany (OECD 2011, Rock et al. 2014), it is likewise of interest to get further insight to what extent children's SES is related to their physical fitness.

Thus, the present thesis refers to the following objectives: (1) to generate physical fitness percentiles for 9- to 12- year-old boys and girls using a longitudinal approach and in line with this to analyse the age- and sex-specific development of physical fitness, (2) to investigate the long-term effect of living area and sports club participation on physical

fitness development in healthy third- to sixth-grade primary school students, and (3) to examine associations between SES and physical fitness in a large and representative (i.e., for a German federal state) sample of healthy third grade primary school students.

## 2. Explanation of terms

### 2.1 School-aged children

There is no generally accepted definition of the term school-aged children. For instance, in the administrative and everyday language a school-aged child is defined as “[...] under 16 years of age and required to be enrolled at a school.”(Queensland 2015); “aged 4+ years” (University of Cambridge 2015); “[...] old enough to go to school.” (CollinsDictionary.com 2015); “[...] 5-8 year-old.” (Goldfarb et al. 2011), and “[...] 6-12 years.” (Child Development Institute 2015, Stanford Children’s Care 2015). The latter is in line with the U.S. National library of medicine that defines ‘school-aged children development’ as “[...] expected physical, emotional, and mental abilities of children ages 6 to 12.” (NLM), 2014).

In the scientific context the term school-aged children is particularly used transdisciplinary according to concepts of stages of development in humans which exemplary displaced the course of development (e.g., physical, social, mental characteristics). With the aim of highlighting developmental specifics (e.g., start of sexual maturity) these concepts delimitate the different stages of development from each other. In doing so, age or school grades (hereinafter used interchangeably with the term class) are most frequently used as determinants for distinction. However, surely due to national differences in school systems (e.g., start of compulsory school attendance) and diverse concepts of stages of development, the term school-aged children encompasses different age spans that result in a variety of scientific based definitions, too. In German-speaking areas the definition of school-aged children is primarily based on the concept of stages of development by Martin (1982). Martin (1982) summarizes the age span of 7-11/12 years in girls and 7-12/13 years in boys as school-aged children. This age span is determined by the time that children start attending school (i.e., 1st grade) up to 5th/6th grade in girls and 6th/7th grade in boys. The end of this stage reflects the onset of sexual maturity that is known to occur in girls earlier (Malina et al. 2004). Accordingly, the developmental stage of school-aged children is divided into early school-aged children (7-10 years, 1st to 3rd grades) and late school-aged children (girls: 10/11-11/12 years, 3rd/4th to 5th/6th grade; boys: 10/11-12/13 years, 3rd/4th to 6th/7th grade). The implicated age spans of both stages are further cited as middle-children age and late-children age, respectively (Winter & Hartmann 2007). It has to be noted that the concepts of stages of development are useful for practice but do not have an explanatory value for changes in development (J. Baur 2009, Martin 1982, Winter & Hartmann 2007).

In the present thesis the term school-aged children is used in the same way as described by Martin (1982). Furthermore, it is specified in consideration of the characteristics of the German school systems, especially the educational act in the German

federal state of Brandenburg (i.e., the federal state where the thesis-based studies were conducted) (Ministry of Education 2007). Concerning the start of compulsory education and the six years of primary school in the federal state of Brandenburg, school-aged children are commonly regarded as 6 to 12 year old children who attend a primary school (i.e., grades 1 to 6). Owing to governmental exceptional cases (e.g., early schooling, repeater), the age span can broaden up from 5 to 13 years. Of note, the present thesis regards children attending grade 3 (study 3, cross-sectional approach) and grades 3 to 6 (study 1 and 2, longitudinal approach). That refers to boys and girls from 8/9 to 12/13 years.

## 2.2 Theoretical concept of physical fitness

Mainly due to its essential importance to individual's health (see 3.1) the term physical fitness is frequently used in scientific fields as well as in everyday life. However, it seems that the everyday use caused that physical fitness became an umbrella term. The question arises to what degree this is negligible (especially in everyday-life themes) and/or whether a clear understanding of what physical fitness represents is of value. As early as in the late eighties Pate (1988) stated that an overabundance of labels (e.g., motor performance, motor fitness, health fitness) in context of the meaning of physical fitness highly impeded the attempt to achieve a consensus concerning a definition of physical fitness (Pate 1988).

With respect to the present thesis it is of particular attention to operationalize the term physical fitness. By doing so, the development of the meaning of physical fitness and its assessment will be included and features a transition to the following paragraphs. Physical fitness represents a multifactorial hierarchical concept which can be defined as a state of being that (1) enables people to carry out daily, primarily physical-related, activities with vigor and alertness without undue fatigue, with sufficient reserve to enjoy active leisure, and is further (2) related to present and future health outcomes (PCPFS 2000, IOM 2012, Malina et al. 2004, Pate 1988, Safrit & Wood 1995).

Several components/indices that can be measured indirectly by means of field based physical fitness tests contribute to the concept of physical fitness and provide the quantitative basis for the assessment of an individual's physical fitness (e.g., high/low fitness). However, literature reveals more or less meaningful differences regarding the number and structure of these components. In general, physical fitness encompasses the components of *cardiorespiratory fitness*, *muscle endurance*, *muscle strength*, *muscle power*, *speed*, *flexibility*, *agility*, *balance*, *coordination*, *reaction time*, and *body composition*. Table 1 provides definitions of individual components. Additionally, according to equal characteristics (e.g., muscle work), single components are grouped under global terms, e.g., musculoskeletal fitness, motor fitness.

Making sure no confusion arises with regard to language similarity of several terms and their (presumed) synonymous use in the scientific literature as well as in the present thesis,

the following should be clarified. The term *cardiorespiratory fitness* (CRF) is frequently used synonymously with the terms cardiorespiratory endurance, cardiovascular fitness, aerobic fitness, aerobic capacity, aerobic power (physical work capacity [ $\text{VO}_2\text{max}$ ]) and endurance (PCPFS 2000, Ortega 2014). Some authors also use the terms *dimension* (Boreham & Riddoch 2001), *motor abilities* (Graf et al. 2004, Janković, 2014, Pate 1988) or *physical qualities* (Castillo-Garzón et al. 2006) instead of *component* of physical fitness.

Furthermore, *musculoskeletal fitness* is similarly denoted as *muscular fitness* or *muscular function* (Shephard 1985, Smith et al. 2014). The combination of indices of muscular fitness and motor fitness - by including flexibility - is also referred to as *neuromotor fitness* and indicates a common distinction of physical fitness with CRF on the other side (Runhaar et al. 2010, Twisk et al. 2000).

**Table 1:** Definition of the main physical fitness components.

fitness components	definition
<i>cardiorespiratory fitness</i> (CRF)	Ability of the body to perform high-intensity activity for a prolonged period without undue physical stress or fatigue. <sup>1</sup> Overall capacity of the cardiovascular and respiratory systems. <sup>2</sup>
<i>musculoskeletal fitness</i>	
- muscular endurance	Ability to resist repeated contractions over time or to maintain a voluntary contraction for a prolonged period of time. <sup>3</sup>
- muscular strength	Ability of a specific muscle or muscle group to generate force. <sup>3</sup>
- muscular power/ explosive strength	Ability to carry out a maximal, dynamic contraction of a single muscle or muscle group on a short period of time. <sup>3</sup> (see the term ‘power’ <sup>4</sup> below)
<i>motor fitness</i>	
- agility	Ability to rapidly change the position of the entire body in space with speed and accuracy. <sup>3</sup> A combination of speed, balance, power and coordination. <sup>2</sup>
- balance	Ability to maintain equilibrium while being stationary or moving. <sup>4</sup>
- coordination	Ability to use the senses, such as sight and hearing, together with body parts in performing motor tasks smoothly and accurately. <sup>4</sup>
- speed (of movement)	Ability to perform a movement within a short period of time. <sup>4</sup>
- power	Ability that relates to the rate at which one can perform work. <sup>4</sup> Ability to exert muscle force quickly. <sup>5</sup>
- reaction time	Ability that relates to the time elapsed between stimulation and the beginning of the reaction to it. <sup>4</sup>
<i>flexibility</i>	Ability of a specific muscle or muscle group to move freely through a full range of motion. <sup>3</sup> ; Ability to move a joint through its complete range of movement. <sup>6</sup>
<i>Body composition</i>	Health-related component that relates to the relative amounts of muscle, fat, bone, and other vital parts of the body. <sup>4</sup>

Notes: <sup>1</sup>Heath (2009); <sup>2</sup>Ortega et al. (2008); <sup>3</sup>Ortega et al. (2014); <sup>4</sup>Caspersen et al.(1985); <sup>5</sup>Howley & Franks (1997); <sup>6</sup>ACSM (2013)

Of note is that the components of physical fitness differ in their importance to athletic performance (e.g., agility in sports like rugby and soccer) versus general health (e.g., cardiorespiratory fitness as basic concept of daily activities).

Since the mid-1970’s, with first occurrences in the USA, the positive effects of physical fitness on health rather than exclusively the athletic performance became an issue (Services 1996). This caused a meaningful realignment of the concept of physical fitness to health and the subdivision of physical fitness into *health-related (physical) fitness* and

*performance- or skill-related fitness* (Blair, Falls & Pate 1983) (Table 2). In most instances the terms *performance-related fitness* and *skill-related fitness* are used interchangeably in the literature (PCPFS 2000). Contrastingly, Lloyd et al. (2015) differentiated between skill- and performance-related components of fitness without clarifying their understanding of terms and the fitness components that are underlined by examples. One can surmise that skill-related fitness refers to the ability to perform a specific athletic skill (e.g., basketball throw), while performance-related (physical) fitness is more related to a fundamental movement skill (e.g., throwing) that has a bigger significance to daily/general activity (further see 2.2.2). However, the term performance-related fitness is obviously dominant and also used in the present thesis in a general context (i.e., unless otherwise specified by reference). Following the classification by Caspersen et al. (1985), health-related fitness includes the components *CRF*, *muscular endurance* and *strength* (combined under the global term muscular fitness (cf. ACSM 2013), *body composition*, and *flexibility*. On the other hand, skill-related fitness includes *agility*, *balance*, *coordination*, *speed*, *power*, and *reaction time*. The authors only briefly noted that ‘the five health-related components of physical fitness are more important to public health than the components that are related to athletic ability (i.e., skill-related fitness).’ (Caspersen et al. 1985, p 128).

**Table 2:** Components of physical fitness and specification of health-related physical fitness.

term/ concept	physical fitness	<sup>HR</sup> physical fitness					<sup>HR</sup> fitness
		Caspersen et al. (1985)	Malina et al. (2004)	Ruiz et al. (2009)	IOM (2012)	ACSM (2013)	
<i>component</i>							
CRF	x <sup>HR</sup>	x	x	x	x	x	x
m. endurance	x <sup>HR</sup>	x	x	x	x	x	x
m. strength	x <sup>HR</sup>		x	x	x	x	x
m. power			x	x		x	x
agility	x <sup>SR</sup>		x			x	x
balance	x <sup>SR</sup>		x			x	x
coordination	x <sup>SR</sup>		x				x
speed	x <sup>SR</sup>		x			x	x
power	x <sup>SR</sup>						
reaction time	x <sup>SR</sup>						
flexibility	x <sup>HR</sup>	x		x	x		x
Body composition	x <sup>HR</sup>	x	x	x	x		x
metabolic							x

*Notes.* CRF = cardiorespiratory fitness; <sup>HR</sup> = health-related; <sup>SR</sup> = skill related; m = muscular; dotted lines highlight classification of components according to equal physiological characteristics.

### 2.2.1 Health-related physical fitness

By the immense increase in research on relations between physical fitness and health outcomes (e.g., cardiovascular disease risk factors) in the last quarter-century (see chapter 3.3) the strong linkage of physical fitness to health and its promotion evolves and further



affects the view of health-related physical fitness components and their underlying concept of physical fitness per se (Bouchard & Shephard 1994, IOM 2012, Pate 1988, J R Ruiz et al. 2009). Herein, the former study research focused on the relation between CRF and health extended to further physical fitness components (e.g., musculoskeletal fitness). In this context at least two current classification branches of health-related physical fitness have to be mentioned.

Firstly, irrespective of the previously general allocation of fitness components according to their (assumed) importance to health or athletic performance as underlined above, those physical fitness components with evidence-based relation to health are filtered out of overall physical fitness components. Ortega and colleagues (2014, 2008) captured CRF, musculoskeletal fitness and motor fitness (i.e., speed, agility, and balance) under the main health-related physical fitness components. In addition, they referred flexibility to the musculoskeletal fitness component (ibid 2014). Secondly, with respect to Bouchard et al. (2012), the term *health-related physical fitness* seems to be either displaced by the term *health-related fitness* (i.e., absence of the notation *physical*) or - which might be more probable - becomes one part of a new, independent and comprehensive concept of health-related fitness (see following paragraph). Bouchard et al. (2012) combine five main groups of components under the term health-related fitness: morphological fitness, cardiorespiratory fitness, muscular fitness, motor fitness and metabolic fitness. Each component encompasses further traits/ factors. In this concept, the muscular fitness component encompasses power, strength, and endurance of a muscle or muscle group. Motor fitness encompasses agility, balance, coordination, and speed (of movement). Finally, body composition (as non-performance measure of physical fitness) is grouped as one among other factors (e.g., bone density) of morphological fitness (Bouchard et al. 2012).

As depicted in Table 2, body composition is a traditional component of physical fitness. Nevertheless, some authors question its inclusion as a component of health-related physical fitness (PCPFS 2000, Ortega et al. 2014). For example, Ortega et al. (2014) considered body composition and included concepts like obesity as health outcome itself. Research reviews that broached the issue of the relation between physical fitness and health confirm this view of obesity as health outcome itself (e.g., Smith et al. 2014). This may also argue in favor of an understanding of the term health-related fitness as a superior concept within which health-related physical fitness components (see Table 2) are only one out of several independent components (e.g., morphological fitness) that are associated to health and are likely interrelated (cf. Boreham & Riddoch 2001).

Even if different approaches to health-related physical fitness exist (i.e., its main components/factors), the literature reveals a broad consensus according to its common definition as 'a state characterized by an ability to perform daily activities with vigor and by traits and capacities that are associated with a low risk for the development of chronic diseases and premature death' (Bouchard et al. 2012, Ortega et al. 2014, Pate 1988, J R Ruiz et al. 2009). Bouchard et al. (2012, p 15) added that health-related fitness '[...] refers to those components of fitness that are affected favorably or unfavorably by habitual

physical activity habits and that relate to health status.’ This further emphasizes the relationship between physical fitness and physical activity (see 3.3.1).

### 2.2.2 Performance-related fitness

In conceptual distinction to health-related (physical) fitness, Bouchard et al. (2012) combine those components of physical fitness under the term performance-related fitness that are necessary for optimal work or sport performance. ‘It is defined in terms of the individual’s ability in athletic competition. Performance-related fitness depends heavily on motor skills [e.g., running, jumping, throwing], cardiorespiratory power and capacity, muscular strength, speed, power or endurance, body size, body composition, motivation, and nutritional status.’ (Bouchard et al. 2012, p 14). The fitness-related components of performance are commonly defined as agility, balance, coordination, speed, and reaction time and can be summarized under the term motor fitness (see Table 2) (Ortega et al. 2014, J R Ruiz et al. 2009, J. R. Ruiz et al. 2011). There exists some overlap between the terms motor fitness and *motor abilities*. For instance, Malina et al. (2004) define motor abilities as a combination of several components that permit individuals to perform specific tasks. The authors stated power, speed, agility, and flexibility as examples.

In this context the term *motor competence* has to be noted and briefly defined. Even though there is some confusion in the literature regarding the operational definition of motor competence, particularly according to fundamental movement skills (Cattuzzo et al. 2014, Logan et al. 2012), it can generally be defined as a person’s movement coordination quality when performing different motor skills, ranging on a continuum from gross (e.g., throwing a ball on a target, standing on one leg) to fine motor skills (e.g., finger tapping) (D’Hondt et al. 2009). In a global view, motor competence encompasses all forms of goal-directed tasks involving coordination and control of the human body that underlie a particular motor outcome (Cattuzzo et al. 2014, D’Hondt et al. 2013). Stodden et al. (Stodden et al. 2008), suggests the proficiency in fundamental motor skills including locomotion and object control skills as important aspects of general motor competence. Motor competence in fundamental movement patterns precedes the development of more complex motor skills, such as using skills in combination with each other or in environments that are more dynamic (Castelli et al., 2007).

As displaced in Table 2, there are debates in literature with regard to allocate *power* either to performance-related motor fitness (e.g., Caspersen et al. 1985, Services 1996) or to (mainly) health-related musculoskeletal fitness, by using the more specific synonymous terms muscular power or explosive strength (e.g., Bouchard et al. 2012, J R Ruiz et al. 2009). The cited definitions indicate that one and the same ability is meant. Furthermore, examples that are given to measure *power* by authors which favorite the first allocation are equal to commonly measurements of muscular power/ explosive strength - e.g., vertical jump, shot-putting, and ball throw (PCPFS 2000, Wood 2015). Within the framework of the present thesis the health-related terms muscular power and explosive strength are used for performances which are primarily characterized by the ability to exert maximum muscle strength rapidly (e.g., standing long jump, ball push).

### 3. Literature review

#### 3.1 Development of physical fitness

Overall, physical fitness in children increases with increasing age. The age-related improvement in physical fitness is mainly influenced by growth and maturation that refer to the biological context of human development (Malina et al. 2004). Normal growth and maturation effect changes in components of physical fitness in children independent on a child's physical activity (Malina & Katzmarzyk 2006).

In recent times, an abundance of cross-sectional studies reported age- and sex-specific percentile-norm values of youth. Findings of studies clearly figured out that performance in tests of cardiorespiratory fitness (CRF), musculoskeletal fitness and motor fitness increased over the age period of 6 to (at least) 12/13 years in boys and girls (Castro-Piñero et al. 2009, J. Castro-Piñero et al. 2011, Santos et al. 2014). Herein, boys achieved better results than girls in nearly all physical fitness components, excepted flexibility and balance, where the opposite is notable (José Castro-Piñero et al. 2011, Catley & Tomkinson 2013, Lundgren et al. 2011, Runhaar et al. 2010, Woll et al. 2011). In addition, the magnitude of sex differences frequently increased over time in CRF and musculoskeletal fitness (Castro-Piñero et al. 2009, Catley & Tomkinson 2013). According to the components of physical fitness that were investigated in the underlying studies of the present thesis an overview of performance development by age and sex in CRF, muscular power of the upper and lower body, speed, agility, and flexibility across the age span of 8/9 to 12/13 years will be discussed in turn below.

##### *Cardiorespiratory fitness*

In general, boys and girls enhanced their CRF on a linear course over the age period of 6 to 13/14 years (Malina et al. 2004).

For example, in four different endurance tests (20-m shuttle run [20-m SRT], ¼-mile run, ½-mile run, and 1-mile run) that were conducted in a sub-sample of 8 to 13 year olds, boys and girls from Spain improved their median performance over all age groups (i.e., ages: 8/9, 10/11, 12/13) in all tests (J. Castro-Piñero et al. 2011). Overall, boys' performance increased to a higher magnitude in all tests as compared to girls. Furthermore, boys significantly outperformed girls in all age groups. Findings are in line with those of a cumulative sample of 9 to 12 year old Australians from 15 different studies published between 1985 and 2009 that were tested in 1.6-mile run and 20-m SRT (Catley & Tomkinson 2013). Performance in the 1.6-mile run linearly increased with increasing age in both sexes. The same pattern of performance improvements by age was notable in the 20-m SRT for boys, whereas girls only showed a marginal performance progression from ages 9 to 11 and afterwards maintained performance. Recently, Santos et al. (Santos et al.

2014) stated cardiorespiratory fitness data for Portuguese children aged 10, 11 and 12. Both boys and girls increased performance in the 20-m SRT by age but the increase was less pronounced in girls (25% vs. 19%). By testing on an incremental endurance bike (PWC 170), 8 to 12 year old German boys continuously improved their absolute and relative values of mechanical power (i.e., Watt, Watt/kg), whereas annually progression increased over the age of 10 in particular (Woll et al. 2011). In girls, performance progression in absolute power values was present as well. But girls' relative mechanical power values did not show such a clear pattern. Performance increased from age 8 to 9 and remained stable at age 10. From age 10 to 11 performance improved again and then decreased at age 12 (Woll et al. 2011).

Results from longitudinal studies confirm performance improvements by age. For instance, Mota et al. (Mota et al. 2009) tested 7 year old Portuguese in the 9-min run. Children were retested at age 10. Authors reported a significant increase of running distance covered in 9 minutes over time. This is in line with 20-m SRT data from 8 year old Australians that were tested again at the age of 10 (Telford et al., 2009). The performance increase was significant in boys and girls, whereas boys attained significantly better values than girls at both measurement points.

At least, early research work of Andersen et al. (Andersen et al. 1976) stated differences between longitudinal and cross-sectional data derived by two cohorts with similar demographic characteristics. Specifically, authors tested 8 years old for their maximal oxygen uptake (absolute and relative  $\text{VO}_2\text{max}$ ) over a period of 5 years. This test was conducted once a year (i.e., final measurement at age 12). Parallel to the baseline measurement of the 8 year olds, Andersen et al. likewise tested 10 and 12 years olds, attending the same school, in a cross-sectional approach with the same test once (i.e., combined longitudinal/cross-sectional study). Linear regression analyses of cross-sectional data (i.e., 8, 10 and 12 year olds) were computed to generate estimate values for the ages 9 and 11. A comparison between both samples highlighted that children in the longitudinal sample showed considerably higher values than expected by the cross-sectional reference data. The differences were statistically significant at ages above 10 years for both boys and girls.

#### *Muscular power of upper- and lower body*

During the school-age years, performance in upper and lower body muscular power increases in boys and girls. Sex differences are relatively small but consistent during this age span and show higher values for boys than for girls (Malina et al. 2004). Nevertheless, current cross-sectional studies report that performance differences between boys and girls are statistically meaningful in favour of the former group (Casajus et al. 2007, Castro-Piñero et al. 2009, Runhaar et al. 2010, Woll et al. 2011) For instance, Castro-Piñero et al. (2009) tested, inter alia, children aged 8 to 13 for upper- (basketball throw [BT]) and lower- (standing long jump [SLJ], vertical jump [VJ]) muscular power. Children were classified in age groups of two consecutive years (i.e., 8 to 9, 10 to 11, and 12 to 13). In both sexes performance increased with increasing age, whereas males' performance was significantly better in all age groups. With respect to the 50<sup>th</sup> percentile, increase of

performance (i.e., 8/9 to 12/13 years) in upper and lower body muscular power were higher in boys than in girls. Sex-specific increases of performance were rather dominant for SLJ (boys: 32%, girls: 28%) and BT (boys: 70%, girls: 65%) compared to VJ (boys: 52%, girls: 41%). In addition, the magnitude of sex differences increased over time in all three tests. In general, sex differences in physical fitness tests that refer to throwing performance are bigger than for tests that refer to other basic skills like jumping (e.g., SLJ) and running (e.g., 20-m sprint) (Malina et al. 2004). Catley and Tomkinson (Catley & Tomkinson 2013) reported performance improvements (reference: 50th percentile) in the SLJ and the BT for a sample of 9 to 12 year olds. Increase of percentage from age 9 to 12 was slightly bigger in girls than boys for SLJ (15% vs. 13%) and, on the other side, slightly bigger in boys than girls for BT (36% vs. 33%). In both tests, boys outperformed girls at ages 9, 10, 11 and 12 (analysis of significance were not reported). The magnitude of sex-differences slightly increased in the BT only, with no clear pattern for the SLJ.

Similarly, 8 to 10 year olds showed increased performance with increasing years, whereas, related to median values, performance growth was nearly equal in boys (12%) and girls (11%) (Roriz De Oliveira et al. 2014). Again, boys' performances were better as compared to girls and showed a trend of increase over the years.

### *Speed*

The literature revealed an improvement in running speed performance across the age span of 8 to 12 years in both sexes with negligibly better values in boys (Catley & Tomkinson, 2013; Malina et al., 2004; Milanese et al., 2010; Roriz De Oliveira et al., 2014). For instance, in a recently published study boys and girls aged 8, 9, and 10 showed a decrease in time needed to run 50-yards with increasing age (Roriz De Oliveira et al. 2014). Annual improvements were constant in boys (4%). Girls improved their performance from 8 to 9 years to the same magnitude as boys (i.e., 4%) with a slightly higher percentage of increase from ages 9 to 10 (6%). Nevertheless, there was a trend of better performances in boys than girls in all age groups that refer to time differences of 0.3s to 0.5s. Milanese et al. (Milanese et al. 2010) reported significantly higher velocity in the 30-m sprint in favour of boys aged 8 to 12. Children were classified in age groups of 8-9 and 10-12. The average velocity of 10-12 years old boys and girls was higher than that of 8-9 year old peers. Girls showed a higher percentage of increase than boys (12% vs. 8%). The latter was likewise reported by Catley and Tomkinson (Catley & Tomkinson 2013) for a sample of 9 to 12 year olds. For both sexes, an annual performance improvement was notable in the 50-m sprint with a more than two times higher total percentage of increase in girls as compared to boys (11% vs. 4%). However, boys at all ages needed 0.2s to 0.5s less to finish the run. A current study, conducted in 8 European countries, stated (already) better performance in boys and girls that related to the second half-year of 8 years olds (i.e., 8.5 to < 9.0 years) than peers with an age of 8.0 to 8.4 (De Miguel-Etayo et al. 2014). Related to median value, older boys and girls were 0.3s to 0.2s, respectively, faster than their younger counterparts.

### *Agility*

Comparable to speed, performances in agility slightly improve from age 7/8 to 12 in boys and girls, whereas boys show somewhat better performances (Casajus et al. 2007, Malina et al. 2004, Roriz De Oliveira et al. 2014, Runhaar et al. 2010). For example, Casajus et al. (Casajus et al. 2007) tested 7 to 12 year olds for their agility by 10x 5-m shuttle run. Children were grouped by ages 7-8, 9-10, and 11-12. Furthermore authors classified children by body mass index (BMI) in normal weight, overweight, and obese students. Irrespective of BMI-status boys and girls in older age groups significantly outperformed children in the younger age groups. In addition, boys at all ages needed significantly less time to finish the shuttle run when compared with girls.

With regard to the normal weight group, boys and girls showed equal percentages of increase in performance over the age groups (14%). Percentage of increase over time in overweight and obese groups was little lower with higher rates of increase in boys (overweight: 11 to 13%, obese: 10 to 14%).

Runhaar et al. (Runhaar et al. 2010) likewise used the 10x5-m shuttle run for testing 9 to 12 year olds for agility. Again, boys and girls showed decrease in mean values with increasing age, with the exception of 12 years old girls that scored equally to 11 year old peers. Magnitude of improvement from ages 9 to 12 was homogenous for both sexes (5%). Boys showed significantly better performances over all age groups (-0.4s to -0.7s).

More recently, Roriz De Oliveira et al. (Roriz De Oliveira et al. 2014) reported that the time needed to perform a 4x10-m shuttle run decreased with increasing age in 8, 9 and 10 year old children. Again, the magnitude of improvement was similar in boys (6%) and girls (5%). Overall, girls needed 0.6s to 0.8s more to finish the shuttle run than boys.

### *Flexibility*

Literature clearly highlights better performance in proxies of flexibility in favor of girls across youth (Haywood & Getchell 2009, Malina et al. 2004, Santos et al. 2014).

Malina resumed that mean scores of sit- and-reach tests are stable from 5 to 11 years of age in girls and then increase markedly during adolescence. In contrast, flexibility performance among boys declines linearly with age from 5 years onwards with a nadir at age 12 and increases during adolescence (Malina et al. 2004).

However, with respect to ages 8/9 to 12/13 current percentile-norm values derived from cross-sectional studies revealed incongruent results in terms of performance development by age within sexes. For instance, Woll et al. (Woll et al. 2011) stated consistent performances in 9 to 12 year old boys and girls in the stand-and-reach test, whereas girls showed significantly higher values in all age groups than boys. Of note, Woll et al. (Woll et al. 2011) likewise reported stable performances of flexibility for the total study sample that encompassed participants aged 4 to 17.

By means of the sit-and-reach test, study findings of Castro-Piñero (José Castro-Piñero et al. 2011) and Catley and Tomkinson (Catley & Tomkinson 2013) are closely in line with the summed-up study results reported by Malina et al. (Malina et al. 2004). In detail, Castro-Piñero (José Castro-Piñero et al. 2011) observed consistent mean values for the age groups of 8-9 and 10-11 in girls that were followed by an increase in performance

at age 12-13. Performance in boys slightly decreased from ages 8-9 to 10-11 and, equal to girls but with a weaker magnitude, increased at age 12-13. Girls consistently outperformed their male peers. Secondly, Catley and Tomkinson (Catley & Tomkinson 2013) reported a slight and linear decrease of median values in boys from ages 9 to 11 and a stagnation in performance from age 11 to 12. However, taking into account further study data up to age 17, boys' performances linearly improved from ages 13 to 17. In girls, performance decreased negligibly from 9 to 10 years of age and then markedly increased up to age of 15. Girls of all ages performed better than boys.

A study by Runhaar et al. (Runhaar et al. 2010) likewise investigated the flexibility of 9 to 12 year old boys and girls by the sit-and-reach test and figured out contrasting results for girls. While boys' mean performance decreased from ages 9 to 11 and then tended to stagnate, girls showed a performance increase from ages 9 to 10 with stable values at age 11 and a slight decrease in performance at age 12. In accordance to aforementioned studies, girls achieved significantly better values. Furthermore, Roriz De Oliveira (Roriz De Oliveira et al. 2014) recently observed enhanced performance in the sit-and-reach test with increasing age in boys aged 8, 9, and 10. Girls likewise linearly increased their performance from 8 to 10 years. Again, performances in girls were better than those of boys at all ages.

## 3.2 Modifying factors' association to physical fitness

In addition to the aim of promoting children's physical fitness in a daily life context, the relation between physical fitness and lifestyle factors that - at least in theory - can be modified are of particular interest. Generally, modifiable factors are classified in behavioral (e.g., diet, physical activity habits, media use) and environmental (e.g., socioeconomic status, living area) subcategories. These factors can be crucial in enhancing and maintaining physical fitness in youth and adulthood.

On the following pages the modifying factors like living area, sports club participation, and socioeconomic status will be reviewed regarding their relation to physical fitness.

### 3.2.1 Living area

Within the context of urbanization, as one consequence of social change (i.e., modification of regularities of social living), the environmental factor of living area gained importance according to its relation to youth's physical fitness in the last centuries. Urbanization can be defined as a radiation and an increase of urban specific lifestyles, economies, and behavioral patterns (Bähr 2011). This implies that the urban industrial ways of life, economic systems, and types of living situations spread across rural environment of advanced economy countries, too. For instance, access to media like internet and television, that foster sedentary habits, is available in rural areas of industrial countries today. On the other side urban areas are increasingly faced with the fact of built environment.

At least until the turn of the millennium, the popular opinion, especially in Germany, existed that children living in rural areas are physically fitter and are likewise less frequently diagnosed as *support needed* than urban living peers and that this difference in fitness performance is highly determined by unfavorable changes in lifestyle habits of urban living children (e.g., frequent computer use, decrease in outdoor playing) (Brandt et al. 1997, Gaschler 2000). It was suggested that rural living children are more physical active and more involved in playing outside due to the natural possibilities that are associated with rural environment (e.g., free space, no dangers by traffic) as well as a lack of further social-change determined leisure time activities that first became a topic in urban environments (e.g., media use). Thus, the rural residential area may positively affect children's physical fitness status and development. For instance, Brandt et al. found significant higher values in favor of rural living 7 to 10 years olds for balance (one-legged stance) and muscular endurance of the body backside ('Spannbogen'). In general, children from rural residences scored higher in 10 of 12 conducted test items than urban peers. Nevertheless, the author revealed that differences in favor of rural residents were not as distinct as was found in a study with the same test items in 7 to 10 year olds ten years earlier (i.e., 1985).

By the use of tests for abdominal muscular endurance (sit-ups), upper-extremity muscular power (ball throw), endurance (600-m run) and flexibility ('upper body swing'),



Heinecke (Heinecke 1992) reported a higher percentage of first and second graders with movement disorders living in urban areas as compared to rural living students (50% vs. 34%). Additionally, in context of a narrative review approach, Gaschler (Gaschler 2000) summarized that in the time period of 1980 to 2000 about one quarter to one third of German primary school students living in urban areas showed movement disorders whereas the percentage of rural living students was about one tenth. However, due to the aforementioned ongoing process of urbanization it might be of interest if the higher physical fitness in favor of rural living school aged-children still exists in recent times – not only in Germany.

Reviewing the studies that refer to the topic of the *modifying impact of living area on physical fitness in children* within an international frame during the last 15 years, a summing up is first of all restricted to cross-sectional studies and secondly, variegated with regard to the tendency of results that were observed. The first fact implies that the topic based review can only bring into focus potential differences in physical fitness of children living in urban areas in comparison with rural living peers. To what extent residential area by itself predicts potentially detected differences on physical fitness cannot consequently be clarified. Table 3 briefly depicts the results of national, European, and international cross-sectional studies that compared urban and rural living school-aged boys and girls by their physical fitness in at least three fitness parameters.

**Table 3:** Study comparison by urban – rural differences in physical fitness of school-aged children<sup>[1]</sup>.

urban vs. rural	N	Age (years)	tests (#)	CRF	muscular fitness				motor fitness			
					strength	power	endurance	agility	balance	coord.	speed	flex.
<i>no differences</i>												
Bös et al. (2009)	3,895	6-17	7	X		X	X		X; X	X		X
<i>no clear differences</i>												
Tsimeas et al. (2005)	607	12	7	X	R ♀; X ♂	R ♀; X ♂ U ♂; X ♀		X			X	X
Chillon et al. (2011)	2,569	7-16	7	R	R; R	X	U	U				U
Pena Reyes et al. (2003)	708	6-13	6	X	R	U	U	U			X	X
Ujevic et al. (2013)	2,431	11	5	R		U	U				X	X
<i>if, then pro rural</i>												
Adamo et al. (2011)	179	9-13	3	R	X							X
Dollman & Norton (2002)	1,231	10-11	4	R	X	X					R ♀; X ♂	
Karkera et al. (2013)	650	9-13	3	R			X					R
Özdirenç et al. (2005)	172	9-11	7	X		X	R; X			X		R; R
Wang et al. (2013)	134,546	9-12	3		R		R					X
<i>pro rural</i>												
Tambalis et al. (2011)	71,227	8-9	4	R		R; R						R
<i>pro urban - adolescents</i>												
Andrade et al. (2014)	648	11-16	9	U	X	U	U; X	U	X	U		X
Lovecchio et al (2015)	14,897	11-14	3		U	U	U					U

Notes: <sup>[1]</sup> Inclusion criteria: published between 01/2000-07/2015 and reporting data of both sexes for at least three physical fitness tests; CRF = cardiorespiratory fitness; coord. = coordination; R = rural; U = urban; ♂ = boys; ♀ = girls.

With respect to the possible findings when comparing physical fitness by living area categories (i.e., pro urban, pro rural, neither or inconsistent) only a small proportion of studies detected no or unclear differences in physical fitness between urban and rural living children (Bös, Worth et al. 2009, Chillón et al. 2011, Pena Reyes et al. 2003, Tsimeas et al. 2005, Ujevic et al. 2013). For instance, Bös et al. (2009) reported no residentially-based differences of performances for the basic physical fitness components of cardiorespiratory fitness (CRF), muscular fitness, motor fitness (i. e., balance, coordination), and flexibility in a nationwide representative sample of German Youth (4-17 years). Tsimeas et al. (2005) resumed that the place of residence had no clear impact on the physical fitness in 12 year old Greeks. Specifically, with respect to the seven fitness parameters that were applied, only three out of the 14 possible cases (i.e., separated by sex) were significantly different between urban and rural children, and these differences were not uniformly distributed in children living in either urban or rural environments.

This is mainly in line with a study of Mexican first to sixth graders (6-13 years) that were tested for distance run (depending on age: 8 or 12-min run), 35-yard dash, hand grip strength (HGS), standing long jump (SLJ), sit-ups (SU), and sit-and reach (SR) (Pena Reyes et al. 2003). Most of the significant differences between living area categories showed no stability in terms of sex or age group (i.e., 6-9 years and 10-13 years) or a total drift concerning better results for one of both area categories occurred (e.g., better CRF in 6-9 year old girls from rural areas as well as in 10-13 year old girls from urban areas). Nevertheless, urban children achieved better results in abdominal muscular endurance (SU) and power (SLJ), whereas rural counterparts scored higher in body size controlled muscular strength (HGS, not significant in 6-9 year boys).

Over a wide age span, Chillón et al. (2011) tested Spanish children and adolescents (7-16 years) for the role of living area on CRF (20-m shuttle run [SRT]), muscular fitness (HGS, SLJ, bent-arm hang [BAH], SU), speed/agility (5 x 10-m shuttle run), and flexibility (SR). The area comparison stressed high inconsistency. In detail, no living area differences (adjusted to age and sex) were detected in one test only (SLJ). In the remaining six tests the living area comparison pointed out a fifty/fifty distribution. Rural youth showed better health-related fitness concerning CRF and muscular endurance and strength of the upper extremities (HGS, BAH) than their non-rural counterparts that scored higher on measures of flexibility, speed/agility and abdominal muscular endurance (SU).

The majority of research is characterised by studies that did not observe continuous location-specific differences in physical fitness (i.e., differences in all conducted physical fitness tests). But when differences occurred, these were caused by better scoring of rural residents (Adamo et al., 2011, Dollman & Norton, 2002, Karkera et al. 2013, Özdirenç et al. 2005, J. H. Wang et al. 2013). For example, using multiple regression analysis, Dollman & Norton (Dollman & Norton 2002) resumed that living area was independently associated with CRF (1-mile run) in both 10 and 11 years old Australian boys and girls (2.5% and 6.7% of total explained variance, respectively), with rural children outperforming their urban counterparts. In addition, girls' running speed was predicted by living area (approximately 1.3% of variance) in favour of rural residents. No predictability of location

on test performances was observed for boys' running speed (50-m sprint) as well as for proxies of muscular power (SLJ) and strength (HGS) in boys and girls.

Results of better CRF for children living in rural areas compared to urban dwellers were supported by several publications later (Adamo et al. 2011, Karkera et al. 2013, Kriemler et al. 2008, Tambalis et al. 2011). For instance, 9 to 13 years olds living in rural areas of India and Kenya, respectively, reached significant higher scores in the 20-m shuttle run test as compared to urban counterparts. Similarly in Europe, studies reported that Swiss and Greek children from rural areas outperformed their urban peers in the 20-m SRT (Kriemler et al. 2011, Tambalis et al. 2011).

Controversially, Özdirenç et al. (Özdirenç et al. 2005) found no performance gain for rural located Turkish children (9-11 years) in the 20-m SRT in comparison to urban children. Indeed, the authors reported that rural children performed significantly better in flexibility (SR, side bending test), and abdominal muscle endurance (SU), while differences by location in CRF (20-m SRT), balance (flamingo balance), and former tests of muscle endurance (BAH) and power (VJ) did not reach significance level.

Within the scope of a nationwide survey of 8 to 9 year olds' physical fitness in Greece, Tambalis et al. (Tambalis et al. 2011) reported overall better physical fitness in children living in rural than in urban areas. Tests encompassed measures of muscular power of the upper (1-kg ball throw) and lower extremities (vertical jump), speed (30-m sprint) and, as aforementioned, CRF (20-m SRT). Findings of another nationwide survey on children's physical fitness in Taiwan (Republic of China) confirm the results of Greece (J. H. Wang et al. 2013). Nine to 12 year old students were tested for abdominal muscle endurance (bent leg curl up), lower extremity muscle power (SLJ), and flexibility (SR). With the exception of flexibility, which did not differ by living area, rural children outperformed their urban peers.

Nevertheless, some study findings speak with regard to a performance gain in urban children during the transition from childhood to adolescence ( $\geq 11$  years) as compared to rural ones (Andrade et al. 2014, Lovecchio et al. 2015, Sandercock et al. 2011). In fact, in a sample of 10 to 15 year old English boys and girls Sandercock et al. (2011) reported no differences in 20-m shuttle run results by residential area for the age group of 10 to 12 years, whereas the older study participants (13-15 years) living in urban environments reached significantly higher scores compared to rural living peers. However, no further tests were conducted which limits the predication of overall physical fitness. In a currently published cross-national study, Lovecchio and colleagues (2015) tested 11 to 14 years olds from Croatia and Italy for muscular fitness (SLJ, SU) and flexibility (SR). They resumed a better physical fitness of urban youth compared to their rural counterparts.

### 3.2.2 Sports club participation

The engagement in a sports club appears to play an important role in moderating physical fitness in school-aged children. However, up to date only few studies investigated the association between physical fitness and the status of sports club participation in school-aged children. These studies continuously observed a better physical fitness profile in children participating in a sports club when compared to non-participating peers (Ara et al. 2006, Drenowatz et al. 2013, Vandorpe et al. 2012, Zahner et al. 2009). For example, Zahner et al. (2009) reported significantly higher performance in first grade students (6-7 years) with an active sports club membership for the fitness components CRF (20-m SRT), strength (sum z-score of 1-kg ball push, jump-and-reach, sit-ups, and bent-arm-hang), coordination (sum z-score of balancing backwards and throw-on-target), and speed (sum z-score of jumping sideward, 20-m sprint, and plate tapping) as compared to non-members. With the exception of speed, significant fitness differences in favor of children participating in a sports club were found in fifth graders (10-12 years), too. Findings are in line with results from a sample of nearly 1,000 German second graders aged six to eight. Drenowatz and colleagues (2013) observed significantly better results in children participating in a sports club (i.e., at least once a week) for measures of CRF (6-min run), upper-extremity muscular power (medicine ball throw), coordination (throw-and-turn), and balance (one-leg balancing) as compared to their non-participating counterparts. Comparably to the results of fifth graders who were tested in the study of Zahner et al. (2009), differences between participating and non-participating second graders in favor of sports club participants did not reach significance level for measures of speed (20-m sprint) and agility (obstacle run: box-boomerang-test). Of note is that the authors found no performance differences between sports club members that participated once or twice per week and those who participated more than twice per week (Drenowatz et al. 2013).

Taking into account that growth and maturation specific changes in body height, body mass and body composition reduce the effectiveness of the aerobic system from childhood to adolescence, Ara et al. (2006) reported that male sports club members maintained their body mass adjusted performance on CRF (relative VO<sub>2</sub>max estimated by 20-m SRT), and muscular strength (relative maximum isometric force during leg extension in squat jump position) which they achieved at nine-year-olds (i.e., prepubescent status: Tanner  $\leq$  2) at the age of 12 years (i.e., Tanner III-IV) when tests were repeated. In contrast, the non-participating comparison group (i.e., no sports club participation during the study period) showed a significant decrease in CRF and muscle strength scores. However, Ara et al. (2006) only analyzed data for differences between pre-test and post-test (i.e., students' unpaired t-test), but not for a potential interaction effect of sports club participation on physical fitness development (e.g., analysis of variance with repeated measures on age).

To the best of the author's knowledge there exists only one study that analyzed the effect of sports club participation on the development of the physical fitness component coordination (Vandorpe et al., 2012). Over a 3 year longitudinal approach, Vandorpe et al. (2012) tested 301 primary school age children who were six- to nine-years old at initial

testing, for their gross motor coordination (i.e., motor quotient of balancing backwards, moving sideways, jumping sideways, and hopping over) once a year. With regard to the factor sports club participation, the children were classified in *no participation* ( $n = 45$ ), *partial participation* (i.e., being at least one year a club member during study period,  $n = 46$ ), and *consistent participation* ( $n = 210$ ). The authors revealed a significant main effect of sports club participation, with children in the no-participation group having a significantly worse motor quotient than the partial-participation group ( $p = .004$ ) and the consistent-participation group ( $p < .001$ ). In addition, the group that reported to be consistently engaged in organized sports over the study frame outscored the partially-participating group ( $p = .043$ ). Nevertheless, Vandorpe and associates (2012) stated that continuous sports club participation did not positively influence the time course of motor development (interaction effect of time x sports club participation:  $p = .74$ ).

### 3.2.3 Socioeconomic status (SES)

The socioeconomic status (SES) is a complex, multidimensional concept used to describe individuals' social and economic position in relation to others (Ditton & Maaz 2011). There are different methodological approaches to operationalize the SES, dealing with the questions 'What kind of social and economic characteristics - denoted as components/dimensions - are included (e.g., education, occupation, property, ethnic group)?', 'Which level of assessment is chosen (e.g., individual, municipality, or national data)?', 'What system of classification is used? (continuous values vs. determined number of SES-groups), and 'How is the SES-index computed (e.g., different weighting of included components)?'. Nevertheless, the most commonly used SES indicators in public health research are education, income and occupation (Ditton & Maaz 2011, Matthews & Gallo 2011). Irrespectively of disparities in the operationalization of SES, evidence indicates that school-aged children living under conditions of limited economic and social capital (i.e., low SES), especially in industrialized nations, are faced with more unfavorable appearances on constitutional components of health like diet (Batty & Leon 2002, Janssen et al. 2006), sedentary behavior activities (Brodersen et al. 2007, Fairclough et al. 2009, Gorely et al. 2004), overweight/obesity (Kleiser et al. 2009, Lobstein et al. 2004, Noh et al. 2014), physical activity (Borraccino et al. 2009, Federico et al. 2009), and cardiovascular disease risk factors (at the time of the study [Van Lenthe et al. 2001] and in later life in particular [Bowen 2010, B. Jackson et al. 2004, Lehman et al. 2005, Melchior et al. 2007]).

Regarding the health determinant physical fitness, only a small amount of studies investigated to what extent a relation to the SES exists in youth, especially in school-age children. In addition, it has to be mentioned that among these studies the assessment of physical fitness was often restricted to measures of cardiorespiratory fitness (CRF) and reported findings demonstrate incongruence.

For example, Kristensen et al. (2006) compared CRF (Vo<sub>2</sub>max by progressive maximal cycle ergometer test) of 8 to 10 years-olds attending third grade in Danish schools in terms of different SES background. A dichotomous classification of their mother's occupational status in blue- (low SES) and white-collar workers (high SES) was used to indicate children's SES. The authors stated significantly higher mean values of Vo<sub>2</sub>max in boys and girls of high SES than of low SES counterparts. Further, percentage of children with low CRF (i.e., lowest sex- and age-specific quartile) was twice that in boys of low SES (32%) compared to high SES peers (16%,  $p < .05$ ), whereas the higher percentage of low-fit girls in the low SES group (31%) only tended to be significantly different from the percentage found in high SES group (21%,  $p < .09$ ). Furthermore, the main amount of the 503 third graders examined were retested at grade nine (14-16 years,  $n = 384$ ). By means of longitudinal data Kristensen et al. (2006) could outline that the relative risk of being low-fit at grade nine was significantly higher in children with low SES in comparison with high SES children (Odds ratio = 1.77,  $p = .034$ ). Although not statistically meaningful, third graders with low SES had even a higher relative risk of maintaining (OR = 1.36,  $p = .511$ ) and developing (OR = 1.94,  $p = .069$ ) low CRF over the six-year time period than children in the high SES group.

Mutunga et al. (2006) support the finding concerning higher CRF in favour of children with high SES for a sample of 2,016 Northern Ireland adolescents aged 12 and 15. Youth's CRF was characterized by estimated  $\text{VO}_2\text{max}$  of a 20-m shuttle run test (20-m SRT). To determine low and high SES, the authors modified the 5-scale UK standard occupational classification for maternal details by respectively combining occupational/social classes I & II (i.e., high SES) and IV & V (i.e., low SES). Recalling that results were not reported by age and sex separately, the high SES group achieved significantly higher scores than the low SES group. It has to be noted, that Mutunga et al. (2006) further detected significantly higher scores of physical activity habits (assessed by questionnaire) in the high SES group than in the low SES group. However, bringing forward the argument that such differences may lie on the causal pathways which mediate SES differences in the dependent variables (e.g., physical fitness, overweight) they did not include physical activity as a confounder of the relation between physical fitness and SES in their statistical analyses.

Results of Mutunga et al. (2006) are of special interest according to recent trends linked with an increase of socioeconomic inequalities (OECD 2011) that may have a harmful impact on physical fitness in children by decreasing SES.

In detail, 10 years prior to the study conducted by Mutunga et al. (titled *Young Hearts Study 2000 in Northern Ireland*), Van Lenthe and colleagues (Van Lenthe et al. 2001) firstly tested a cohort of 12 years-olds ( $n = 509$ ) within the same framework (titled *Young Hearts Project in Northern Ireland*). Three years later, students were tested again (age 15 years). At this time (early nineties), the authors found no significant differences in CRF (finished laps in 20-m SRT) for study participants at the age of 12 and 15 in terms of SES. However, the mean score of both boys and girls in the high SES group tended to be better than in low SES groups. Of note, the operationalized SES differed between both studies. Van Lenthe et al. (2001) used the occupational status of the parent with the main family income (high SES = non-manual occupations, low SES = manual occupations) as an index of SES. Just as in the study of Mutunga et al. students were questioned for physical activity habits. Van Lenthe et al. (2001) indicated no differences in males' physical activity by SES, whereas differences among girls were at borderline significance at the age of 12 ( $p = .06$ ) and significantly at age 15 ( $p \leq .05$ ) - in each case showing higher physical activity in girls of high SES. Thus, as mentioned above, the comparison of both studies may detect that the relation between SES and physical fitness (and even furthermore mediating factors like physical activity) is gaining in importance according to socioeconomic changes in daily life.

In one of the few studies that examined the relation between children's SES and a variety of physical fitness components, Freitas et al. (2007) summarized no fitness gain in Portuguese students with high SES. The physical fitness assessment of 7- to 18-years old boys and girls encompassed tests of CRF (12-min run), musculoskeletal fitness (standing long jump [SLJ], handgrip strength [HGS], sit-ups [SU], bent-arm hang [BAH]), balance (flamingo stance), speed/agility (10x 5-m shuttle run, plate tapping), and flexibility (sit and reach [SR]). The SES index was classified in low, middle, and high SES based on a sum score including parental information concerning the 5 dimensions occupation, education, income, housing, and residential area. Focusing on the findings for the age groups of seven



to nine years and of 10 to 13/14 years significantly poorer performances in the male high SES group were found for CRF (7-9 years), muscular endurance (BAH) (10-13 years), flexibility (10-13 years), and speed (plate tapping) (7-13 years) compared to low and/or middle SES-groups. Girls with high SES scored significantly lower in abdominal muscular endurance (SU) (7-9 years) than peers with middle SES. On the other side, better balance performance was found for students in the high SES-group (boys: 10-11 years, girls: 7-9 years) compared to students in the low and/or middle SES-groups. With respect to these results, SES primarily related to physical fitness in males and to a less extent in females.

The variation of the relation between physical fitness and SES by sex was resumed in a more current study too. In contrary to the findings of Freitas et al. (2007), Vandendriessche et al. (2012) revealed in about 2000 Flemish boys and girls aged 6 to 11 a stronger relation between physical fitness and SES for girls. Specifically, by means of a motor coordination test battery (i.e., 'Körperkoordinationstest für Kinder', including jumping sideways, moving sideways on boxes, hopping for height on one leg, and balancing backwards) the authors found significantly higher performance in single items (except moving sideways) and the transformed motor-quotient in girls with high SES than girls with middle and/or low SES. In boys' motor performances no SES-related differences occurred. The SES was applied by occupational status of both parents/legal guardians and grouped in low, middle and high. In this study also children filled in a questionnaire in terms of potential sports club participation (yes vs. no) and accumulated hours spending in organized and non-organized sport activities per week. Latter was included as covariate for all statistical analyses. Physical activity in sports participation was significantly higher in high SES girls and likewise the amount of girls participating in a sports club increased with higher SES. Results were equal in boys, whereas the differences between high and middle SES group did not reach significance. In addition to motor fitness, children were tested for CRF (20-m SRT), muscular strength (HGS), power (SLJ, counter movement jump), and endurance (knee push-ups [PU], SU), speed/agility (10 × 5-m shuttle-run), and flexibility (sit and reach [SR], shoulder). The tendency of a stronger relation between physical fitness and SES in girls than in boys was also given for these fitness components. While significant performance differences by SES in boys were only present for the SU-test in favor of high SES, girls of the high-SES outperformed their peers of the middle- and low-SES in CRF, speed/agility and abdominal muscular endurance (SU, only low SES), and shoulder flexibility.

The more prominent differences between SES groups and markers of physical fitness in girls as compared to boys are supported by studies with adolescent participants (Bohr et al. 2013, Fahlman et al. 2006, Jiménez Pavón, Ortega, Ruiz, Chillón, et al. 2010, Jiménez Pavón, Ortega, Ruiz, España Romero et al. 2010). For example, in 6 to 8 graders only in girls differences in physical fitness in relation to SES were present. Bohr et al. (2013) observed significantly better performances in measures of CRF (20-m SRT) and muscular endurance (curl-ups [CU], PU) in favor of high SES females. Students were classified either in low or high SES depending on the allowance to participate in a federal free lunch program. Independently on sex, no SES-related performance differences occurred in flexibility (SR).

Recently, Jin and Jones-Smith (Jin & Jones-Smith 2015) stated better physical fitness in a sample of approximately 1.6 million fifth-, seventh-, and ninth-graders of the U.S. state of California for pupils with high SES in comparison to their low SES counterparts. In accordance to Bohr et al. (2013) authors classified children's SES according to eligibility for National School Lunch Program that is related to family income (high SES: no eligibility, low SES: eligibility). Physical fitness was computed as a sum score of the Fitnessgram® test battery with respect to passing healthy fitness zone in six fitness components that are (1) CRF: 1-mile run or endurance run/walk; (2) abdominal muscular endurance: CU; (3) upper-body muscular endurance: PU, modified pull-ups or BAH; (4) body composition: skinfold measurements, BMI, or bioelectric impedance analyser; (5) trunk extensor muscular strength and flexibility: trunk lift, and (6) flexibility: back-saver sit-and-reach or shoulder stretch.

Lastly, a few studies dealt with the relation between physical fitness and SES in German children (Ahnert 2005, Bös, Worth et al. 2009, Klein et al. 2011; Koch 2009, Prätorius & Milani 2004). While Ahnert (2005) observed no relation between motor coordination (cf Vandendriessche et al. 2009) and SES in a sample of Munich children tested in 1988, 1990 and 1992 at the ages of 8, 10, and 12, findings from studies around the 2000s point out a tendency of higher physical fitness with increasing SES. For example, within the framework of the *German Health Interview and Examination Survey for Children and Adolescents (KiGGS)*, girls with high SES aged 6 to 13 achieved significantly higher values in PU, SLJ, flamingo balance, balancing backwards, jumping sideways (not for 6-10 years), and SR in comparison to peers with low SES (Bös, Worth et al. 2009). High SES boys partially outperformed their low SES counterparts in cycle ergometer tests (not for 6-10 years) and SLJ only (not for 11-13 years). SES-index included maternal and paternal information regarding education, occupation, and income. Prätorius and Milani (2004) tested 163 children aged 6 to 13 living in two different districts in a large West German city for their motor coordination (cf Vandendriessche et al., 2009) and balance (measurement of center of pressure [CoP] by one legged-stance). Districts were categorized into low and high SES-areas according to specific economic and social indicators of the inhabitants (i.e., percentage of recipients of basic security benefits for job seekers and social welfare, percentage of foreigners, residential space per capita, and living space). Children living in the high SES-district had a significantly better motor coordination (motor index) and balance (CoP in posterior direction and forefoot displacement) than peer residents in the low SES area.

### 3.3 Physical fitness and health

#### 3.3.1 Benefit of physical fitness on health

With respect to a public health approach, the necessity of physical fitness testing is highly caused by the assumption of a positive relation between physical fitness and enhanced health. Thus, the linking between physical fitness and various health outcomes (e.g., adiposity, cardiovascular disease, and metabolic disorder) is risen up to a powerful topic in scientific research within the last two decades. In relation to this topic it has to be pointed out that health is a multifactorial construct with a physical, mental and social domain. The World Health Organisation defined health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” (WHO 2006). The definition has not been amended since 1948 and is up to now criticized and discussed concerning its absoluteness of the word *complete* in relation to *well-being* (Godlee 2011, Larson 1999). One proposal for a redefining was devised by a consortium of international health experts in 2009, defining health as “the ability to adapt and to self-manage” (Huber 2010, Huber et al. 2011). The definition of health by Bouchard et al. (2012) picks up this view, too, and stresses that health moves within a continuum with positive and negative poles. Herein, positive health is associated with a capacity to enjoy life and withstand challenges. On the other side, negative health is associated with morbidity and, in the extreme, with premature mortality (Bouchard et al. 2012). The health indicators that are principally studied in terms of their relation to physical fitness in children (and youth in general) focused on the physical domain of health. However, mental health, also denoted as psychological health, receives more and more attention. On the following pages the beneficial impact of children’s physical fitness on their present and future health is highlighted. The overview encompasses the mainly studied health indicators until now. These are adiposity, cardiovascular disease (CVD) and metabolic (syndrome) risk factors, bone health, mental health, and cognitive ability. In general, the benefit of physical fitness on health can be emphasized in three links:

- (1) The direct, cross-sectional, relation between current status of physical fitness and health;
- (2) The causal, longitudinal, relation between physical fitness and health - i.e., the effect of developmental variations of physical fitness (especially improvements) on changes in health outcomes over time;
- (3) The behavior and biological carry-over effect of physical fitness on health - i.e., the predictability of children’s physical fitness on health outcome in later life.

A special case of a behavior health indicator that relates to physical fitness is represented by physical activity. On the one hand, comparably to physical fitness, physical activity is likewise a predictor of health (Janssen & Leblanc 2010, Steele et al. 2008). On the other hand physical fitness may act as a predictor of physical fitness (Pahkala et al. 2012) and

often mediated the relation between physical fitness and health. Therefore, finally the relation between physical activity and physical fitness will be briefly depicted.

### *Adiposity*

Relating to a recent systematic review that indicates the health benefits of muscular fitness for children and adolescents, Smith et al. (2014) resumed a strong evidence for an inverse relation between indices of muscular fitness (MF) and adiposity in children and adolescents, whereas the association was dominant both for total adiposity (e.g., body mass index [BMI], sum of skinfold thickness [SSF]) and central/abdominal adiposity (e.g., waist circumference [WC]).

A currently published study of 10 to 15 year olds supports these review results (Peterson et al. 2014). Children's muscle strength, estimated by hand grip strength test (HGS) showed a moderate correlation with the percentage of body fat (BF) (boys:  $r = -0.51$ , girls:  $r = -0.50$ ). By classifying the muscle strength performance into tertiles-groups (i.e., low, moderate, and high strength), the authors stated that indicators of adiposity (i.e., BF, BMI, WC, and waist-to-hip-ratio [WHR]) significantly decreased with increasing muscle strength fitness tertiles in both sexes. Further, children's cardiorespiratory fitness (CRF) (7-min run) was inversely correlated with BF, albeit with a weaker magnitude (boys:  $r = -0.32$ ; girls:  $r = -0.32$ ) (Peterson et al. 2014). In a sample of about 1,400 six to thirteen year olds, Nassis et al. (2005) observed that a high level of CRF (20-m shuttle run test [20-m SRT]) positively affected the amount of BF, independently on an unfavorable BMI status. Specifically, within the sub-sample of overweight or obese participants it was resumed that those who reached a high CRF level ( $\cong 4^{\text{th}}$  and  $5^{\text{th}}$  quintile) showed a lower percentage of BF and SSF as compared to overweight/obese peers who were classified as unfit ( $\cong 1^{\text{st}}$  and  $2^{\text{nd}}$  quintile) (Nassis et al. 2005). In addition, a study by Graf et al. (2004) noted an inverse relation between the BMI- status of about 700 German first graders and their general dynamic coordination. The fitness component of coordination was aggregated as a motor quotient (i.e., sum score) by a standardized gross motor coordination development test battery (balancing backwards, one-legged obstacle jumping, jumping from side to side, and sideways movements) (Graf et al. 2004). The findings revealed that the motor quotient of obese and overweight children was worse than the motor quotient of normal-weight and underweight children. For the sake of completeness, children were further tested for their CRF (6-min run), whereby groups of obese and overweight children also significantly differed in performance from the normal-weight and the underweight ones (i.e., less running distance).

Based on a systematic review, Ruiz et al. (2009) summarized that CRF in childhood and adolescence is a strong predictor of central and overall adiposity later in life. Furthermore, the authors noted evidence that changes of muscular strength from childhood to adolescents are negatively associated with changes in overall adiposity (J R Ruiz et al. 2009). The latter is confirmed and extended with regard to further fitness components by new findings (Rodrigues et al. 2013). Specifically, over a 9 year time interval, six year olds were tested for MF (standing long jump [SLJ], bent arm hang [BAH], sit-ups [SU]), speed (50-m dash), and CRF (20-m SRT) five times. Independently on sex, better results (i.e.,

improvements) in any test predicted a less body fat deposition over the years (Rodrigues et al. 2013). Lastly, a 4-year longitudinal study of approximately 2,800 children attending 1<sup>st</sup> to 7<sup>th</sup> grade at baseline stressed the positive impact of changes on overall physical fitness on predicting the maintenance or achievement of healthy BMI status (BMI: “healthy weight” <85<sup>th</sup> percentile  $\geq$  “overweight/obese”) (Hruby et al. 2012). Children conducted tests for CRF (20-m SRT), agility (4 x 10-m shuttle run), muscular endurance (curl ups [CU], pull ups or BAH), and flexibility (sit and reach [SR]). By the use of Healthy Fitness Zone [HFZ] of Fitnessgram® a binary overall fitness score was generated to distinguish between fit (i.e., achieving HFZ in all items) and underfit students (i.e., who did not achieve HFZ in at least one test). In the one to four years of follow-up, underfit overweight/obesity children that achieved the fit-category were nearly 3 (boys) to 5 (girls) times more likely to achieve normal weight compared to constant underfit overweight peers. Furthermore, initially fit overweight/obese boys and girls were 12 and 2 times, respectively, more likely to achieve healthy-weight if they maintained their overall-fitness status. A preventive effect of fitness was also reported as fit healthy weight children at baseline had a 4 times higher relative chance to maintain healthy weight compared to children who lost their fit-status across study time frame. On average, for every increase in the number of fitness tests passed between two successive years, there was a statistically significant decrease in the subsequent year’s BMI Z-score (Hruby et al. 2012).

#### *CVD and metabolic (syndrome) risk factors*

Owing to its pre-eminence as a cause of death (WHO 2014), CVD and the risk factors predisposing to CVD are apparently the most extensively studied ones in relation to physical fitness in adults. As there is no longer any doubt that CVD is partly a pediatric problem and that the onset of cardiovascular disease lies in childhood (Froberg & Andersen 2005, Kavey et al. 2003), in recent years research escalated to the cohort of children more and more. Of course, studies at this lifespan are restricted to examine risk factors for CVD rather than for occurrence of disease or death arising by such disease.

CVD is caused by disorders of the heart and blood vessels, and includes coronary heart disease (CHD) cerebrovascular disease, raised blood pressure, peripheral artery disease, rheumatic heart disease, congenital heart disease and heart failure (WHO 2015). Risk factors of CVD are classified in modifiable (e.g., age, gender, socioeconomic status) and non-modifiable. The majority of CVD risk factors belong to the first category, including: high blood pressure, high cholesterol/lipids, raised blood glucose, overweight/obesity, tobacco use, unhealthy diet, and physical inactivity (WHF 2015, Mendis et al. 2011).

The metabolic syndrome is defined as a group of health condition that multiplies a person’s risk for CVD. There is general concern that metabolic syndrome is present if 3 of the following 5 conditions ( i.e., risk factors) occurred: abdominal adiposity, high triglyceride level, a low high-density lipoprotein cholesterol level, high blood pressure, and high fasting glucose (NHLBI 2015).

Comparably to adiposity - also a single risk factor of CVD - Smith et al. (2014) reviewed strong evidence for an inverse relation between MF and clustered CVD risk as well as MF and single CVD and metabolic risk factors. For example, the study of Benson et al. (2006) stated a moderately inverse relation between both single and sum score of muscular strength of upper (i.e., bench press) and lower body (i.e., leg press) and estimated insulin

resistance (IR) in children aged 10 to 15 ( $r = -0.42$  to  $-0.55$ ). Of note, the study likewise included a measure of CRF (treadmill test) that was related to IR, too ( $r = -0.57$ ). Furthermore, the authors classified the upper body muscular strength score (i.e., MF indicator that was highest correlating to the health outcomes) and CRF score into fitness tertile-levels (i.e., low, moderate, high fitness group). Both moderate and high muscular strength groups were 98% less likely to develop IR than the group of low muscular strength. Reaching high CRF levels was, similarly to MF, associated with protection from higher IR (95%), whereas a moderate level of CRF was not protective (2%). Of interest, when analyses were adjusted to CRF, results of considerably lower relative risk of IR in moderate (93%,  $p = .05$ ) and high (98%) muscle strength groups compared to low muscle strength group almost remained the same. After controlling CRF-risk-analyses for MF, only high CRF level showed a protective effect for IR (93%). These results hint at a positive impact of MF and CRF on IR independent on the performance expression of the other physical fitness component (i.e., CRF or MF). It has to be recapitulated that even moderate/average MF seems to be (approximately to the same magnitude like high MF) a powerful marker of preventing IR (Benson et al. 2006). Interestingly, a review by Artero et al. (2012) equally indicated a significantly inverse relation between muscular strength indices and indices of IR, clustered cardiometabolic risk, and inflammatory proteins in youth, even if analyses were adjusted for CRF indicators.

Recently published studies confirm the strong evidence of a relationship between MF and the cardio-metabolic risk profile in children as outlined by Smith et al. (2014) (Diez-Fernandez et al. 2015, Peterson et al. 2014). In detail, in a sample of nearly 1,200 children aged from 8 to 11 a moderately inverse relation between the MF score of performance in HGS and SLJ and an index of cardiometabolic risk factors was reported ( $r = -0.41$  to  $-0.51$ ) (Diez-Fernandez et al. 2015). In addition, computed MF score quartiles (i.e., quartile 1  $\hat{=}$  low; quartile 2 and 3  $\hat{=}$  middle; quartile 4  $\hat{=}$  high) illustrated that a higher level of MF was associated with lower cardiometabolic risk. A similarly linear relation in terms of a more favourable cardiometabolic risk score with increasing MF tertile-levels (HGS; strength level: low, moderate, high) was found in 10 to 15 years youths ( $n = 1,421$ ) (Peterson et al. 2014). The association was likewise independent on individuals' CRF (7-min run).

Furthermore, a high CRF level (cycle ergometer) can positively modify the unfavourable impact of BMI on the magnitude of a metabolic syndrome (MetSyn) risk score (DuBose et al. 2007). Specifically, using median split to classify 7 to 9 year olds in low ( $<$  median) and high ( $\geq$  median) CRF level, DuBose et al. (, 2007) reported that a high CRF level in overweight children resulted in a lower (i.e., better) MetSyn score when compared to overweight children with low CRF, whereas the correlation between CRF and MetSyn score was moderate ( $r = -0.41$  to  $-0.47$ ). Furthermore, the MetSyn score was not significantly different among the *normal-weight & low CRF-group* and the *at-risk-for-overweight & high CRF-group*. In general, the MetSyn score was significantly higher in the low CRF-group compared with the high CRF-group.

The positive impact of high CRF on the risk of CVD and/or metabolic syndrome in children and adolescents, independent on BMI-status, is confirmed by further studies (for a

review see: Steele et al. 2008). In addition, Steele et al. (2008) reviewed that the inverse relation between CRF and CVD and metabolic risk in youth was independent on physical activity. Another review by Ruiz et al. (2009) indicated a strong evidence for the predictability of children's and adolescents' CRF on CVD risk factors later in life (e.g., blood lipids, BP).

Predictability of CRF (treadmill) on the appearance of clustered CVD risk factors for the span of childhood to adolescence was more recently investigated by Bugge et al. (2013). With respect to a seven-year longitudinal time period including three measurements of 434 children at ages 6, 9 and 13, authors revealed that those in the lowest CRF tertile at baseline showed the highest tracking coefficients of clustered CVD risk at all three time intervals (i.e., 6 to 9 years, 9 to 13 years, 6 to 13 years;  $r = 0.50$  to  $0.67$ ) compared to their peers in the middle and high CRF tertiles. Results imply that within the least fit CRF group the stability of unfavorable metabolic health is stronger as compared to that within the most fit CRF group (Bugge et al. 2013).

### *Bone health*

There is strong evidence for a benefit of MF on bone health in children and adolescents (Smith et al. 2014). For instance, 7 to 10 year old girls ( $n = 21$ ) were tested for the relation between a muscle strength score (summed peak torque of the flexors and extensors of knee, trunk, and elbow) and their bone mineral density (BMD) and content (BMC) as well as bone area (van Langendonck et al. 2004). Depending on adjustment of analysis (i.e., to height and skeletal age), van Langendonck et al. (2004) revealed a low to moderately high correlation between muscle strength score and total bodily BMC ( $r = 0.49$  to  $0.73$ ), BMD ( $r = 0.39$  to  $0.45$ ), and bone area ( $r = 0.57$  to  $0.77$ ). With respect to children of a higher age, Wang et al. (Q. Wang et al., 2007) tested 10 to 13 year old girls ( $n = 258$ ) for their upper and lower body strength (i.e., maximal voluntary contraction [MVC] of left elbow flexors and knee extensors) and BMC. Two years later, participants were retested. The BMC of arm and leg moderately highly correlated with upper ( $r^2 = 0.54$ ) and lower ( $r^2 = 0.50$ ) muscle strength at baseline. Furthermore, the two year-change of BMC and MVC was low correlated in the upper ( $r = 0.32$ ) and lower limbs ( $r = 0.22$ ).

More recently, de Moraes et al. (2013) reported a significantly low to moderate relation between quantitative and qualitative measures of bone health and muscular power (SLJ) and muscular endurance (push-ups [PU]) of 11 to 16 year old ( $n = 300$ ) boys ( $r = 0.31$  to  $0.41$ ) and girls (SLJ only,  $r = 0.17$ ). Certainly, when association was adjusted to age, body height and weight, BMI, BF and pubertal status, only boys' performance for muscular power remained significant ( $r = 0.27$ ). Irrespectively of sex, indicators of bone health showed no associations with performance in 20-m SRT and stand and reach test. This is in line with a 3-year follow-up study in soccer-playing boys aged 7 to 9 at baseline ( $n = 104$ ) (Vicente-Rodriguez et al. 2004). Performance improvements in speed (30-m sprint) and explosive strength (vertical jump test), but not CRF (i.e., 20-m SRT), were associated with enhanced bone mass, independent on boys' pubertal status (Vicente-Rodriguez et al. 2004).

Concerning the impact of current physical fitness status on bone health in later life, some evidence is reported that MF as well as CRF in adolescence are significantly associated with BMD at adulthood (Barnekow-Bergkvist et al. 2006). In detail, females' CRF (9-min run) and MF (two-hand lift, hanging leg lift) at age 16 ( $n = 204$ ) predicted 20 years later at the age of 36 BMD in total body (CRF and MF) in legs and bigger trochanter (two-hand lift) as well as in arms (only MF) (Barnekow-Bergkvist et al. 2006).

#### *Mental health*

Recent review of Smith et al. (2014) likewise outlined strong evidence for a positive relation between youth's MF and mental health indicators like self-esteem/physical self-perception, life satisfaction, perceived health, and depressed mood. In addition to reviewed literature, Smith et al. computed a moderate pooled effect size ( $r = 0.42$ ) for the relation between MF and the psychological construct of perceived sports competence (Smith et al. 2014). For instance, the only study reviewed which included children  $\leq 12$  years of age, investigated the relation between muscular (SLJ, 2-kg medicine ball throw) as well as motor fitness (20-m sprint, 30-m sprint, 10 x 5-m shuttle run) and sub-items of self-perception (perceived coordination, sports competence and physical ability, body dissatisfaction) in boys and girls aged 11 to 14 (Morano et al. 2011). Except the 2-kg medicine ball throw, all associations were significant with low to moderate correlation coefficients ( $r = 0.21$  to  $-0.54$ ). Highest association was found for SLJ and perceived sports competence (boys:  $r = 0.51$ ; girls:  $r = 0.45$ ) as well as SLJ-test and body dissatisfaction (boys:  $r = -0.54$ ; girls:  $r = -0.52$ ). In general, relations between MF and self-perception were higher in boys than in girls.

Padilla-Moleda et al. (2012) reported a positive association of CRF (i.e., 20-m SRT) with life satisfaction in children (6-11 years,  $n = 380$ ;  $\beta = 0.14$ ) and adolescents (12-17 years,  $n = 304$ ;  $\beta = 0.17$ ), whereas it was positively associated with perceived health status only in adolescents ( $\beta = 0.15$ ,  $p = .008$ ).

Results of a study in 8 to 11 year olds ( $n = 1,158$ ) confirm the positive link between components of physical fitness and mental health - characterized by 10 health-related quality of life dimensions (Morales et al. 2013). In detail, children were tested for their CRF (i.e., stages of 20-m SRT) and MF (index of HGS and SLJ) and categorized by percentiles (P) in poor ( $< P25$ ), satisfactory (P25–P75), and good ( $< P 75$ ) level of CRF and MF, respectively. Higher levels of CRF and MF were significantly associated with better physical well-being in both genders. Furthermore, children with higher levels of CRF and MF showed better scores for the dimension of social support, and girls with higher CRF-level estimated their self-perception more positive compared to peers. In addition, the index of the health-related quality of life dimensions was more favorable in girls with higher levels of CRF and MF, whereas no significant differences were detected among male fitness groups. Latter indicates that especially girls' perceived quality of life benefited from better CRF and MF (Morales et al. 2013).

#### *Cognitive ability*

Smith et al. (2014) considered inconsistency/uncertain evidence for the relation between MF and cognitive benefits by reviewing six cross-sectional studies that dealt with the topic.



Inconsistency/ uncertainty of evidence refers to the fact that only half of the studies (i.e., 3 of 6) reported a positive correlation between MF and indices of cognitive ability (e.g., academic achievement) in children and adolescents (Coe et al. 2012, Du Toit et al. 2011, Dwyer et al. 2001). For these studies Smith et al. (2014) suggested explanatory power as limited due to a lack of inclusion of important confounders (e.g., sex, age) or an inadequate measure of cognitive ability (Dwyer et al., 2001). The remaining three studies reported no significant relation between MF and indices of cognitive ability (Castelli et al. 2007, Edwards et al. 2011, J. R. Ruiz et al. 2010). Of note in these studies is that participants only belong to period of adolescence (13-18 years) (J. R. Ruiz et al. 2010). Even if Castelli et al. (2007) reported no impact of MF (PU and CU) on academic achievement (i.e., total achievement, reading achievement, and mathematics achievement) in 3<sup>rd</sup> and 5<sup>th</sup> graders (8-10 years,  $n = 259$ ), they still found an impact of CRF (20-m SRT) and the total fitness score (i.e., aggregated z-score of 20-m SRT, PU, CU, and SR) on academic achievement. In brief, higher CRF was positively related to total achievement ( $\beta = 0.43$ ), reading achievement ( $\beta = 0.40$ ) and mathematics achievement ( $\beta = 0.42$ ). Total fitness score was positively related to total academic and reading achievement ( $\beta = 0.43$ ) as well as mathematics achievement ( $\beta = 0.45$ ).

Further notable for the study of Edward et al. (2011) is that the relation between physical fitness and cognitive abilities highly differs among components of physical fitness (and certainly cognition types). As cited above, authors revealed no relation between MF and academic performance in sixth graders (11-13 years,  $n = 800$ ). However, students' CRF (1-mile run) was related to mathematic ability (MAP-score). According to age- and sex- specific norm values by Fitnessgram®, children were classified in three CRF-levels (i.e., improvement needed, Healthy Fitness Zone [HFZ], Exceeding HFZ). Analysis indicated that the MAP-score significantly increased with increasing CRF-level.

Haapala (2013) recently broached the issue of the relationship between CRF and cognition and academic performance in children up to age 13. The author reviewed that CRF is linked to a higher cognitive capacity and to a better academic performance. More specific, Haapala (2013) summed up that higher levels of CRF were mainly associated with a higher performance in tasks that require rigorous attention allocation and the use of attention resources in order to prevent undesirable results and a higher performance in memory tests that involved hippocampal encoding.

In a currently published study, Torrijos-Ninjo et al. (2014) tested 9 to 11 year old boys and girls ( $n = 893$ ) for their CRF (20-m SRT), MF (sum score of HGS and SLJ), and agility (4 x 10-m shuttle run) and analyzed the associations to children's academic grades/marks in core subjects (averaged score of marks in Mathematics, Languages and Literature, Natural, Social and Cultural Sciences, and English). Test scores were categorized by quartiles (Q) ( $Q1 \triangleq$  poor;  $Q2$ - $Q3 \triangleq$  satisfactory;  $Q4 \triangleq$  good), and analyses were adjusted to age and parental education (primary, middle, or university education). The authors reported that, with the exception of boys' MF, academic achievement was overall significantly lower in boys and girls with poor fitness level as compared to peers with satisfactory and good fitness levels (not significant in girls for CRF and MF). Highest effects (i.e., effect sizes [ES]) were indicated for the comparison of poor and good fitness

level in terms of agility/ speed (ES = 0.55 to 0.69) and CRF (ES = 0.31 to 0.81), whereas effects were higher in boys. Further, boys with good CRF and agility fitness levels had a 7 and 4, respectively, times higher probability of scoring in the top quartile of academic achievement (i.e., reference: Q1-Q3) than peers with poor fitness levels. Girls with satisfactory or good agility fitness level had a 4 and 5, respectively, times higher probability of scoring in the top quartile of academic achievement than girls with poor speed/agility fitness level. However, results of Torrijos-Nino et al. (2014) confirm that CRF has a more meaningful or impact at all on academic achievement than MF in school age children.

Up to date, the causal link between physical fitness and cognitive abilities is hardly examined. However, in a 4-year longitudinal approach, London et al. (2011) indicated a predictive function of overall physical fitness (i.e., passing vs. failing fitness tests) on academic achievement (standardized tests of mathematics and English language and arts) in children of two cohorts (a) 4th to 7th (n = 1,325) and (b) 6th to 9th grade (n = 1,410). Overall physical fitness included Fitnessgram® measures of CRF (1-mile run), MF (CU, PU, and modified pull-ups or BAH), body composition (BMI), and flexibility (SR). In both years of measurement (i.e., at grades 4 & 7 or at grades 6 & 9, respectively), children were classified as having passed physical fitness tests if they reached standardized norm values (i.e., HFZ) in at least 5 of 6 physical fitness tests. The authors stated modest evidence for the fact that improved fitness is associated with gains in academic achievement over time. Further, they mentioned that the achievement gap between persistently fit and persistently unfit children begins as early as 4<sup>th</sup> grade, i.e., a year prior to the students' first physical fitness testing, and the academic achievement differences between both groups already existed. Worth to mention, London et al. further revealed a strong evidence of socioeconomic status on the academic achievement. Specifically, youth from low SES backgrounds who did not pass the fitness test are particularly susceptible to the negative relationship between poor fitness and academic performance compared to failures of high SES backgrounds. The latter did not experience as large a negative effect of fitness on their academic performances as those from lower socioeconomic backgrounds.

### *Physical activity*

Physical activity is frequently defined as any “bodily movement that is produced by the contraction of skeletal muscle and that substantially increase energy expenditure (Bouchard et al. 2012).”. It characterizes a behavior that occurs in a variety of forms and contexts, including free play, house chores, exercise, school physical education, and organized sports (Malina et al. 2004).

Thus, there is reason to presume that physical activity and physical fitness are positively linked and that the relationship between physical activity and fitness is causal (i.e., higher PF caused higher PA and vice versa). With respect to a narrative review, Malina and Katzmarzyk (2006) stated that relationships between indicators of physical fitness and regular physical activity exist, but they are generally low or moderate. Additionally, physical activity accounts for a relatively small percentage of the variation in some indicators of fitness in children as well as in adolescents. For instance, indicators of

CRF (1.6-mile run), abdominal muscular endurance (SU), and flexibility (SR) were low or moderate related to estimated energy expenditure (activity report) of 7<sup>th</sup> to 9<sup>th</sup> graders ( $r = 0.23$  to  $0.34$ ) (Huang & Malina 2002). Overall, a maximum of 7% of the variance in fitness indicators was explained by estimated energy expenditure (boys: 2-7%, girls: 0-5%). One reason for the weak associations reported in the study of Huang and Malina (2001) might be the limited validity and reliability of self-reported (i.e., subjective) activity measures in comparison with an objective assessment (e.g., accelerometer). In 9 year olds, Brage et al. (2004) observed a significantly positive interaction between CRF (maximal cycle ergometer test) and objectively measured physical activity (uniaxial accelerometer) whereas the magnitude of correlation was not reported. Within the scope of the European Youth Heart Study, Ekelund and colleagues (2007) reported little associations between CRF (incremental cycle ergometer test) and objectively measured subcomponents of physical activity (e.g., vigorous PA, total PA; uniaxial accelerometer) for children (9-10 years) and adolescents (15-16 years) from Denmark, Estonia and Portugal ( $r = 0.08-0.14$ ).

Indeed, more current studies foster evidence of a positive relation between physical fitness and physical activity and, by means of a longitudinal approach, pointed out the predictive function of physical fitness on activity in particular (Aires et al. 2010, Ciesla et al. 2014, Larouche et al. 2014, Larsen et al. 2014, Lopes et al. 2011). However, not all studies estimated physical activity in an objective way. For example, in a sample of 11 to 19 year olds who were tested for CRF (20-m SRT) once a year over 3 years, it could be shown that annual changes in CRF were positively and independently associated with changes in physical activity (assessed by questionnaire) (Aires et al. 2010). Using the value of first tertile as the cut-off point to distinguish between low (< first tertile value) and high fit group (> first tertile value) at baseline, authors revealed that the fit group were more active in each given measurement point than the low fit participants. Further, the fit students at baseline showed an increase in physical activity over the three years while low fit peers' physical activity decreased. Because it is frequently reported that physical activity decreased at the transition from childhood to adolescence (i.e., at about 10 to 12 years) and within adolescence years (for a review see: Dumith et al. 2011) these findings are of big interest and underline the importance of physical fitness promotion at an early age.

Findings are supported in two ways by younger children of up to 6 years (Lopes et al. 2011). The authors noted that 6 year olds with high gross motor coordination at baseline (motor quotient [MC] of 4 subtests: balancing backwards, one-legged obstacle jumping, jumping from side to side, and sideways movements) (high MC  $\cong$  highest tertile) could maintain their amount of physical activity within the frame of annual testing procedure up to the age of 10, while peers in the low ( $\cong$  lowest tertile) and middle tertile reduced their physical activity over time. Of note, children in the three MC-tertiles did not significantly differ in levels of physical activity at baseline. Thus, the influence of motor coordination appears to amplify over time frame. In addition, as second supporting-way, children's baseline CRF (1.6-mile run) was also indicated as a positive predictor on physical activity level at age 10.

Most currently, *The Childhood Health Activity and Motor Performance School Study-DK* (CHAMP-Study DK) (Larsen et al. 2014) brought to light the positive relation between

components of physical fitness and physical activity. In a three-year longitudinal approach children aged 6 to 12 year at baseline were tested for CRF (Andersen endurance test), muscular strength (HGS) and power (vertical jump [VJ]), and indices of motor fitness (backwards balance, precision throw, 5x 10-m shuttle run [shuttle run]). Children's physical activity (i.e., moderate to vigorous PA per day) was measured by uniaxial accelerometer. Measurements of physical fitness and physical activity were repeated after three years. Authors stated a significantly positive association between baseline test performance and follow-up measure of physical activity for the fitness components CRF, muscular power and muscular endurance ( $\beta = 0.003$  to  $0.06$ ). In addition, children's agility (shuttle run) was significantly inverse associated to their daily moderate to vigorous physical activity three years later ( $\beta = -0.13$  to  $-0.26$ ). Further, a computed z-score of performance-related fitness (i.e., VJ, shuttle run, backward balance, precision throw) showed the highest of all analyzed relation to moderate to vigorous physical activity ( $\beta = 0.58$ , adjusted to sex). Of note, authors also analyzed data in terms of the predictive function of physical activity on physical fitness components and suggested that the clinical importance of fitness components as a predictor of moderate to vigorous physical activity is bigger than vice versa.

### 3.3.2 Tracking of physical fitness

Taken into account that physical fitness is a crucial health outcome by itself, it is of interest to which degree physical fitness tracks over time in youth - independent of a known medical tailored (e.g., secondary prevention of overweight) or leisure time specific (e.g., regular exercise in a sports club) promotion of physical fitness. Physical fitness among children indicates a wide variation that is even risen up within the last decades (Albon et al., 2010; Wedderkopp et al., 2004). If levels of fitness are maintained in a peer related rank order from childhood to adolescence, those children initially observed to be unfit would predictably become unfit adolescents (Malina, 1996). Would that be the fact, it is more important to enhanced physical fitness in children with low fitness. On the other side children that achieve high fitness level may be endowed with motor skills and abilities as well as biological parameters that linked to the process of talent identification and promotion.

The term *tracking* refers to the tendency of individuals to maintain a relative rank within an age-sex group over time according to a certain variable (Malina 1996). So the initial level of a certain variable tends to follow a pattern over time and predicts later levels of the variable in the same individual. This indicates that tracking concerns two different concepts: (1) the stability of a certain variable over time and (2) the predictability of a measurement of a certain variable early in life on values of the same variable later in life (Twisk et al. 2000).

One of the first studies that addressed this topic was the *Amsterdam Growth and Health Longitudinal Study* (Twisk et al. 2000). In the late seventies, 13 year olds ( $n = 181$ ) were initially tested for their CRF (maximal treadmill test,  $VO_2\text{max}$ ) and neuromotor fitness (six tests of muscular strength, speed, coordination and flexibility). The physical fitness tests were repeated 5 times at the age of 14, 15, 16, 21, and 27 years. Across the 15-year period, the authors considered a good stability for neuromotor fitness (stability coefficient  $[\beta] = 0.76$ ) and a low to moderate stability for cardiorespiratory fitness (CRF) (0.31). Of note, the stability coefficient for neuromotor fitness was of the same order as values for body weight (0.70), body fatness (0.63), and serum cholesterol (0.71) and markedly higher than the value for physical activity (0.34). Concerning to the relative risk of reaching or maintaining the low fitness quartile after the 15 year-period, the data revealed that those students that were in the low fitness quartile at baseline had a nearly 4 times (CRF) up to 14 times (neuromotor fitness) higher risk to maintain in the low fitness quartile as compared to counterparts in the other three quartiles at baseline (i.e., swift to low fit).

Focusing on the stability of physical fitness during primary school age years, Janz et al. (2000) annually tested 7 to 12 year old boys and girls for measures of muscular strength (hand grip [HGS]) and CRF (ergospirometry:  $VO_2\text{max}$ , relative  $VO_2\text{max}$ , allometrically adjusted for fat free mass [FFM]) over 5 years. With the exception of the stability coefficient of FFM adjusted  $VO_2\text{max}$ , all stability coefficients were significant with a degree of 0.39 to 0.75 in terms of the comparison between follow up (year 5) and baseline (year 1). Of interest, the variables with the highest degree of tracking tended to be

weight-dependent variables (e.g., peak power, peak grip strength, and unadjusted  $\text{VO}_2\text{max}$ ). This suggests that children's body weight relative to peers remained stable throughout the study period - comparable to the findings of Twisk et al. (2000) in 13 to 27 year olds - and contributed to the high degree of tracking. In detail, CRF-mechanical power (Watt) and muscular strength demonstrated the highest degree of tracking over the five years with correlations ranging from 0.61 to 0.62 in girls and 0.72 to 0.75 in boys.

Similar, Kristensen et al. (2006) observed a high stability of measures of CRF (maximal cycle ergometer test,  $\text{VO}_2\text{max}$ ) in third graders over a six-year time interval (i.e., follow up at grade 9) ( $\beta = 0.50$ ;  $p < .001$ ).

Lastly, Maia et al. (2001) reported a continuously high performance stability among boys aged 12 to 17 years ( $n = 454$ ) over a six year time interval for several measures of MF (vertical jump, arm pull, leg lifts, and BAH), coordination (plate tapping), CRF (20-m SRT), and flexibility (SR) as well as for the aggregated overall fitness score (overall fitness:  $\beta = 0.78$ , estimated variance: 74%, single items coefficients only reported for 12-14 years-interval [ $\beta = 0.78$  to 1.00] and 14-17 years-interval [ $\beta = 0.56$  to 0.91]). The analysis included 3 measurements at age of 12, 14, and 17.

## 4. Research objectives

The preceding paragraphs documented the age- and sex-specific development of physical fitness during childhood (see section 3.1) and summarized the current state of research about the association between children's physical fitness and behaviourally- or environmentally-related factors such as living area, sports club participation, and socioeconomic status (SES) (see section 3.2).

With regard to the increased knowledge about beneficial and detrimental impacts of high/low physical fitness levels on obesity, cardiovascular disease, mental health, cognitive as well as social abilities in children (Haapala 2013, Morales et al. 2013, Ortega et al. 2008, Smith et al. 2014, Steele et al. 2008), its repetitive assessment is essential to provide evidence for significant changes in trends, impact factors, and the need of interventions (i.e., promotion of insufficient fitness and talent identification). In recent years, various (national) fitness surveys provided information on the average physical fitness from childhood to adolescence (Hardy et al. 2011, Tremblay et al. 2010, Woll et al. 2011), and a large amount of studies provided age- and sex-specific percentile values of physical fitness in today's youth (Bös, Schlenker, et al. 2009, Castro-Piñero et al. 2009, J. Castro-Piñero et al. 2011, De Miguel-Etayo et al. 2014, Roriz De Oliveira et al. 2014, Santos et al. 2014, Sauka et al. 2011). Particularly the latter are useful for physical fitness evaluation (e.g., identification of low-/high-fit children and adolescents).

It is well documented that, with the exception of trunk flexibility, children's physical fitness increases during the time span of schooling to the onset of puberty (i.e., school-aged children) (Malina et al. 2004, Milanese et al. 2010). In addition, there is evidence in terms of common sex-specific differences in physical fitness and its development in school-aged children. In brief, studies markedly revealed that boys performed significantly better in physical fitness components of CRF and muscular power (Castro-Piñero et al. 2009, J. Castro-Piñero et al. 2011, Malina et al. 2004, Telford et al. 2009). The better female performance in flexibility is also undoubted (José Castro-Piñero et al. 2011, Woll et al. 2011). Some incongruent findings are reported in terms of age- and/or sex-specific development patterns, e.g., for CRF (Catley & Tomkinson 2013, Roriz De Oliveira et al. 2014) and flexibility (José Castro-Piñero et al. 2011, Gulias-Gonzalez et al. 2014, Woll et al. 2011). In conjunction to these incongruent findings, it has to be noted that the largest part of research has been achieved from cross-sectional studies, especially the reported percentile-related physical fitness data, which indicate a meaningful methodological limitation. In detail, cross-sectional data are potentially subjected to a cohort effect and do not reflect changes experienced by a single individual. Thus, physical fitness should be measured in longitudinal studies, which give the possibility to assess natural changes in individual growth and development and exclude cohort effects.

With respect to the mentioned lack of research, the methodological limitations that arrived from cross-sectional studies, and the public importance of health-

related physical fitness, the first objective of the present thesis is to assess the individual development of physical fitness in healthy 9 to 12 year old boys and girls and to generate age- and sex-specific percentile norms by means of fitness test data obtained from various health- and skill-related physical fitness components. It is hypothesized that children's physical fitness increased with age and that sex-specific performance differences occurred over time.

Concerning the aim of promoting physical fitness by means of specifically tailored intervention programmes, it is of significance to get evidence of determinants in children's daily life that might affect their physical fitness and its development. In this regard, the examination of factors that refer to children's behaviour and environmental living conditions are fundamental research topics. For instance, within the context of urbanization, the environmental factor of living area has gained importance according to its relation to youth's physical fitness in the last decades. Several studies detected an association between children's area of residence and their physical fitness, whereby in most instances it was shown that school-aged children living in rural areas outperformed their urban peers, especially in measures of CRF (Adamo et al. 2011, Dollman & Norton 2002, Karkera et al. 2013, Kriemler et al. 2008, Tambalis et al. 2011). This result seems to confirm the general opinion concerning more free and safety space in rural areas that might foster children's amount in active free play/ physical activity and consequentially their physical fitness. Nevertheless, at this time none of the studies have longitudinally examined whether living area, and hence the presumed more favourable rural living conditions, truly affect child's physical fitness development.

In addition, study results highlighted the positive association between sports club participation and physical fitness. More specifically, children that actively participate in a sports club performed significantly better in physical fitness tests with regard to proxies of CRF, muscular, and motor fitness (Ara et al. 2004, Drenowatz et al. 2013, Vandorpe et al. 2012, Zahner et al. 2009). Even though this is an overall interesting finding, according to the underlined cross-sectional nature the question of causality remains unanswered. This means, it is unresolved whether participating in a sports club accounts for the detected better physical fitness or the fact that physically fit children are more likely to participate in a sports club. In fact, at this time only one study is known that investigated the interaction between the status of sports club participation (classified as no participation, partial participation [i.e., at least one year during study period], and non-participating) and a single component of physical fitness (i.e., gross motor coordination) (Vandorpe et al. 2012). The authors detected no significant interaction effect of the status of sports club participation and the development of coordination in initially 6- to 9-year-olds over a three-year study period.

Related to the missing identification of cause-and-effect relationship, another objective of this thesis is to examine the effect of living area and sports club participation on physical fitness development in primary school students from



grades third to sixth. The first hypothesis was that children living in rural areas show a better development of physical fitness than those living in rural areas. It was further hypothesized that regular participation in a sports club leads to a higher performance development in children's physical fitness during primary-school-aged years when compared to non-participating peers.

At least, research pointed out an inverse association between SES and an unfavourable status in various health outcomes in youth such as sedentary activities, adiposity, and risk of cardiovascular disease (Baquet et al. 2014, Batty & Leon 2002, Fairclough et al. 2009, Noh et al. 2014, Van Lenthe et al. 2001). However, relatively little is known about the potential relation of the SES towards physical fitness in school-aged children. Existing literature revealed some hints of a better physical fitness in children with high SES when compared to those with low SES. Furthermore, it was found that this inverse relation differed between sexes in terms of a more pronounced relation in girls (Bös, Worth et al. 2009, Kristensen et al. 2006, Vandendriessche et al. 2012). It has to be taken into methodological account that the available data relate to (i) studies with a small sample size, (ii) studies that only included measures of CRF, and/or (iii) studies that reported incongruent results (i.e., results differ by the applied physical fitness test).

Particularly, with respect to the recently reported increase of socioeconomic inequalities in Germany, knowledge about the association between SES and physical fitness is important. Thus, the third objective of the present thesis is to investigate associations between SES and physical fitness in primary school-aged children (attending third grade). Two hypotheses were formulated concerning a better physical fitness in children living in high SES communities compared with those living in middle and/or low SES communities and that the association between SES and physical fitness differs between boys and girls.

## 5. Methods

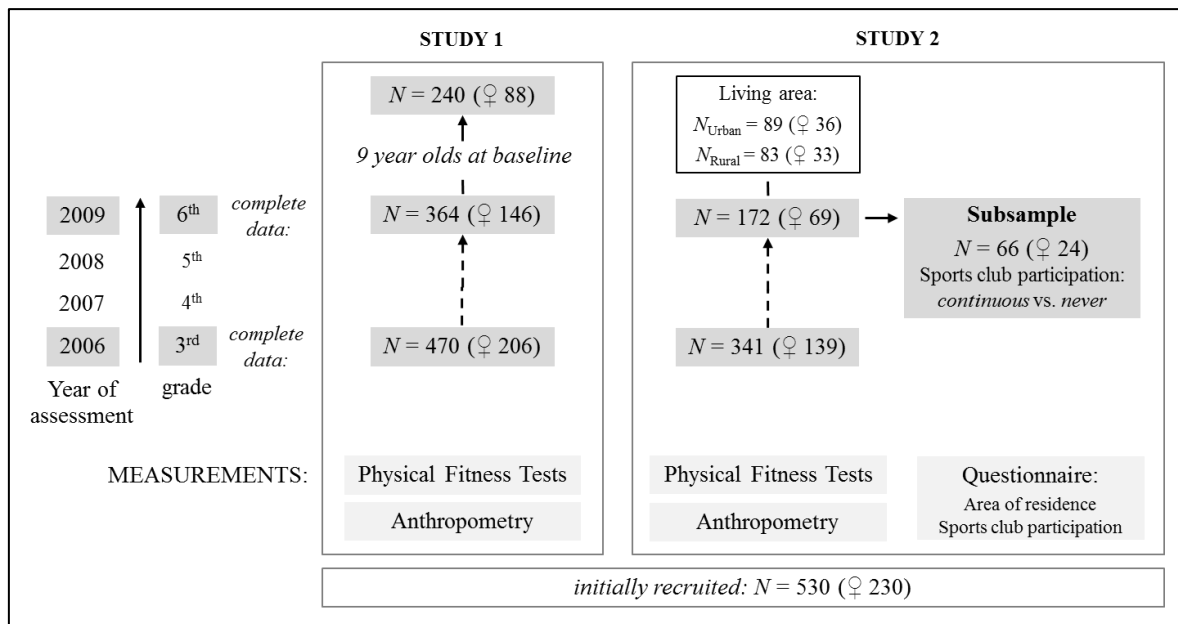
### 5.1 Study design & Participants

The three studies of the present thesis refer to two school-based research projects of which one (*EMOTIKON-Study*) was conducted and the second one (*EMOTIKON-Grundschulsport study*) has still been conducted in the German federal state of Brandenburg. Both studies were approved and funded by the Ministry of Education, Youth and Sports of the federal state of Brandenburg and co-funded by the Sports Federation of the federal state of Brandenburg.

The data of studies 1 and 2 were collected within the framework of the *EMOTIKON-Study* (Wick et al. 2013). This *study* was initialized as a four-year longitudinal study that annually tested primary school students for their physical fitness from grades 3 to 6 (i.e., four measurement time points). The students were attending 29 public primary schools from two out of six school districts of the federal state of Brandenburg (Germany). The two school districts were chosen because of their location (i.e., near vs. distant) to the metropolis Berlin that is linked to socioeconomic conditions (e.g., rates of unemployment figures) and, thus, defined an important specific of the federal state of Brandenburg. The participating schools were randomly selected within both school districts according to the area and settlement structure of the communities in which the schools are located, derived from the *State Development Plan of Brandenburg* of the federal state of Brandenburg (Ministerium für Landwirtschaft 2002).

In addition to physical fitness assessment, the study included measures of anthropometry (i.e., body mass and body height) and information regarding children's status of sports club participation and their place of residence (see 5.3). Only children whose parents or legal representatives provided written informed consent were included. The annual testing period lasted 4 weeks (i.e., from March to April) with the first measurement time point having taken place in 2006 and the fourth and last one in 2009. Five hundred and thirty children were recruited to participate in the study.

Concerning the longitudinally-related research objectives of the present thesis specific sampling procedures were performed to generate the underlying samples of studies 1 and 2 (see Figure 1).



**Figure 1:** Flow chart of the sampling procedure of study 1 and study 2.

### *Study 1 – Physical fitness percentiles*

The final sample of study 1 – generating longitudinally-based physical fitness percentiles of children aged 9-12 years – includes a two-step sampling procedure. In a first step, all children that provided complete (and valid) data in the physical fitness tests and anthropometry parameters for each single measurement time point were selected. Data that were obtained by questionnaire were not taken into account. Of the initially recruited 530 third graders, 470 children (264 boys; 206 girls) attending 28 schools provided complete data in both measurements and thus could be selected for the baseline sample.

For 364 (218 boys; 146 girls) of the 470 students complete data were likewise available for the assessments at the 4<sup>th</sup>, 5<sup>th</sup>, and 6<sup>th</sup> grades (77%). The chronological age with two decimals was calculated for each child as the difference between test date and birth date, where 9.00-9.99 years refers to age group '9 years', for example. The age range of the 364 students at baseline spanned from seven years (one girl), over eight years (53 boys; 48 girls), nine years (152 boys; 88 girls), ten years (10 boys; 9 girls), up to eleven years (three boys). In a second step, only children aged nine (152 boys; 88 girls) at baseline (i.e., cohort with the highest amount of students) were included in the final sample (66% of baseline sample). This selection was due to the fact that computing percentile values in a longitudinal approach is limited to a single age group. The final 240 students were attending 27 schools.

### *Study 2 – Effect of living area and sports club participation on PF*

As outlined in figure 1, 341 (103 boys; 69 girls) third graders fulfilled the inclusion criterion for the baseline sample of study 2 – examining the effect of living area and sports club participation on physical fitness in children from grades 3 to 6. The inclusion criterion was complete (and valid) data in the physical fitness tests, the anthropometry parameters and the questionnaire. A total of 172 (103 boys; 69 girls) students of the baseline sample (50%) annually fulfilled the inclusion criteria up to grade 6. Of these students, no one

changed their residential area during the study period (i.e., continuously belonged to baseline classification of urban or rural area – see 5.3.2). Eighty-nine children lived in urban (53 boys; 36 girls) and 83 children in rural (50 boys; 33 girls) areas. The children were attending 24 schools.

A subsample of the final 172 children was generated in terms of children that *continuously* (33 boys; 16 girls) and children that *never* (9 boys; 8 girls) participated in a sports club over the study period (i.e., grades 3 to 6). The 66 students of the subsample were attending 21 schools.

### *Study 3 – Socioeconomic differences in PF*

Study 3 of the present thesis – investigating the association between physical fitness and socioeconomic status in third graders – is a sub-study of the *EMOTIKON-Grundschulsport*-study [www.emotikon-grundschulsport.de]. The project was initialized in 2010 as an ongoing cross-sectional evaluation of the physical fitness of all children attending grade 3 in public primary schools of the federal state of Brandenburg (i.e., annual evaluation in grade 3). Furthermore, children were questioned for their status of participation in extra-curricular physical education classes and sports clubs (see 5.3). The evaluation of children's physical fitness is noted as an official part of the school curriculum for physical education. Annually, the Ministry of Education, Youth and Sports informed parents in writing of all third graders about the evaluation of their physical fitness (i.e., background, objectives, test procedure, analysis).

Since 2012, the annual testing period has been conducted at the beginning of the respective school year within a four weeks' time frame (i.e., four weeks between September and October). For the research aims linked to study 3 the sample of students, that were tested in 2013, was used for further sampling procedures. This initial sample included 14,041 (7,080 boys and 6,961 girls) children from 375 schools. Of these students, a total of 12,472 (6,296 boys, 6,176 girls) children from 368 schools provided complete (and valid) data for the physical fitness tests and the protocol of organized sports participation. Due to the fact that generating of age- and sex-specific norm values were conducted within the statistical processes, the less amount of children aged 6 (5 boys; 2 girls), 11 (1 boy, 3 girls), and 12 (1 boy) had to be excluded. The chronological age with two decimals was calculated for each child as the difference between test date and birth date (e.g., 8.00-8.99  $\cong$  8 years). Thus, the final sample for statistical analysis included 12,460 children (6,289 boys and 6,171 girls) that refer to 292 (128 boys; 164 girls) 7-year olds, to 9,913 (4,833 boys; 5,080 girls) eight-year olds, to 2,099 (1,226 boys; 873 girls) 9-year olds, and to 156 (102 boys; 54 girls) 10-year olds.

## 5.2 Physical fitness testing

In each study of the current thesis six field-based physical fitness tests were used for testing children's physical fitness (see Figure 2). The tests of both longitudinal studies (i.e., studies 1 and 2) refer to a specific physical fitness test battery (Stark 2000) that assesses five components of physical fitness: *cardiorespiratory fitness* (9-min run test), *muscular power* of the upper and lower body (1-kg ball push test, standing long jump test), *speed* (50-m sprint), *agility* (star agility run), and *flexibility* (stand-and-reach).

These fitness components are further assessed in study 3 in which four different physical fitness tests were taken from different motor fitness test batteries to assess physical fitness. Cardiorespiratory fitness was tested by a shorter time distance run, the 6-min run (Bös 2000, Bös, Schlenker et al. 2009). Muscular power of the upper and lower body was tested by a different version of a 1-kg ball push and the standing long jump, respectively. Speed was assessed using the 20-m sprint. Tests of agility (star agility run) and flexibility (stand and reach) were equal to those carried out in the longitudinal studies. The testing procedure and instruction of tests are subsequently characterized.

Physical Fitness Tests		
Study 1 & Study 2	<i>components of physical fitness</i>	Study 3
<b>9-min run</b>	<i>Cardiorespiratory fitness</i>	<b>6-min run</b>
	<i>Muscular power:</i>	
<b>1-kg ball push</b> » single left and right arm » kneeling position	<i>upper body</i>	<b>1-kg ball push</b> two handed « standing position «
<b>triple hop</b> » single left and right leg » 3 times jump at same leg	<i>lower body</i>	<b>standing long jump</b> with both feet « one jump «
<b>50-m run</b>	<i>Speed</i>	<b>20-m run</b>
<b>star agility run</b>	<i>Agility</i>	<b>star agility run</b>
<b>stand and reach</b>	<i>Flexibility</i>	<b>stand and reach</b>

**Figure 2:** Measurement of physical fitness in the studies of the present thesis.

### 5.2.1 Study 1 & Study 2

In both longitudinal studies the children were tested by researchers that were assisted by supervising university students. All physical fitness tests were performed during official physical education classes on one day at the respective school using standardized test protocols. With the exception of the endurance run that was performed outside, the tests

were carried out in the respective school gyms. Before testing, all students followed a 10-minutes warm-up programme which consisted of light running including coordinative exercises (e.g., side steps, backwards run, skipping), submaximal plyometric exercises, and short-distance sprints.

#### *50-m sprint test*

The 50-m sprint was used to assess speed of movement. The test was performed in a stationary starting position. Participants were instructed to stand in frontal erect posture with one foot right behind the starting line. Students started the first of two trials on the command 'ready-set-go' and accelerated at maximum effort. Time was taken with a stop watch to the nearest 1/10 s. The best trial (i.e., minimal running time) was used for data analysis.

#### *1-kg ball push test*

Muscular power of the upper body was assessed using the 1-kg medicine-ball push test. The test was performed with one's single left and right arm. For the right-handed push, participants set the right knee on the floor with a 90° angle between lower leg and thigh, whereas the left foot stood behind the starting line with a 90° angle between lower leg and thigh of the left leg. The right hand held the ball at the neck. The extended left arm pointed forward at eye level (i.e., pushing direction) (Figure 3a). For the left-handed push the starting position for arms and legs changed, respectively (i.e., right arm pointing forward, left knee on the floor, and right foot at the starting line). In this frontal erect position, participants had to counter-rotate the trunk and push the ball as far as possible (Figure 3b, c). The ball-pushing distance was taken using a measuring tape to the nearest 25 centimeters (i.e., quarter of a meter). Two trials were performed for each arm with a one-minute rest before changing the pushing arm. The best trial in terms of maximal distance for each arm was summed and used for the data analysis.



**Figure 3:** Schematic description of the ball push test (kneeing). (a: starting position, b: counter-rotation of the trunk. c: push action).

#### *Triple hop test*

Muscular power of the lower body was tested using the triple hop test (Figure 4). The participants were instructed to stand with one foot right behind the starting line and to jump three times with the same leg as far as possible and to land on both feet. Subjects were allowed to use arm swing during the tests. Two trials were performed for each leg with a one-minute rest between trials. The best trial in terms of maximal distance from the starting line to the landing point at heel contact for each leg was added and used for statistical analysis. Measurements were taken to the nearest centimeter using a tape measure.



**Figure 4:** Schematic description of the triple hop test.

#### *Stand-and-reach test*

The stand-and-reach test was used to assess flexibility (i.e., flexibility of the trunk and the sciatic crural muscle group) like it is reported in previously published German test batteries (Bös et al., 2004; Rusch & Irrgang, 1994). Subjects were instructed to begin the test in a barefoot standing position on an elevated platform keeping their feet together and both arms extended over their head (Figure 5.a). They were asked to bend over using their maximal range of motion during expiration (Figure 5.b). During the test, knees, arms, and fingers were fully extended for at least two seconds (i.e., recording of value after 2 seconds). A tape measure was attached to the platform with 100 cm corresponding to the upper level of the platform. Values above 100 cm indicate that the person was able to reach beyond his/her toes (i.e., good flexibility). Values below 100 cm indicate that the person was not able to reach his/her toes (i.e., limited flexibility). The best out of two trials (i.e., maximal reaching distance) with a one-minute rest between trials was used for the data analysis.



**Figure 5:** Schematic description of the stand-and-reach test (a: starting position, b: ending position).

#### *Star agility run test*

The participants were instructed to run in different running techniques (e.g., forward, backward, side steps) from the centre to the edge and back of a 9 x 9-m star-shaped field with four spikes (see Figure 9 under 6.1.3). The spikes and the centre of the field were each marked with pylons (height: 30 cm). Starting at the centre of the field, the participants had to run forward to spike 1 (line 1) and backward to the centre (line 2). From the centre, they turned to the right side and side-stepped to spike 2 (line 3), turned to the left side and side-stepped back to the centre (line 4). Upon reaching the centre, students turned backward and ran to spike 3 (line 5) and forward to the centre (line 6). Finally, they turned to the left side and side-stepped to spike 4 (line 7), turned to the right side and side-stepped back to the centre (line 8). During the test, subjects had to touch the top of the pylons at each respective spike and when traversing the centre position. Time was taken with a stop watch to the nearest 1/10 of a second. Subjects performed one practice trial and thereafter two test trials with a five-minute rest in between. The best trial (i.e., minimal running time) was used for the data analysis.

### *9-min run test*

The 9-min run test is a test for the assessment of cardiorespiratory fitness (A. S. Jackson & Coleman, 1976; Turley et al., 1994) (updated: (Padilla-Moledo et al., 2012)). The test was performed outside on a running track of 200 to 400 m of the respective school campus. Participants started their run on the command ‘ready-set-go’. Split time was given every minute. The maximal distance covered during the nine-minute run was used for further data analysis.

### 5.2.2 Study 3

As an official part of the school curriculum, the measurement of physical fitness within the scope of study 3 was performed by the respective physical education teachers during official physical education classes using standardized test protocols. The standardized test protocols (i.e., test instruction and recording) and information concerning the test procedure (e.g., 10-min standardized warm-up prior to testing as conducted in studies 1 and 2) are annually sent to all schools at the beginning of the school year. In addition, the physical education teachers are supervised with the test instruction during community level-based advanced training courses that are provided by the Ministry of Education, Youth and Sports. All tests were performed in the respective school gyms during official physical education lessons. The tests were taken from different motor fitness test batteries to assess physical fitness.

### *20-m sprint test*

In reference to previously published German test batteries the 20-m sprint was used to assess speed performance in a stationary starting position (Bös, 2000; Bös et al., 2001; Bös et al., 2009). Participants were instructed to stand with one foot right behind the starting line in frontal erect posture. On the command ‘ready-set-go’, students started their first trial and accelerated at maximum effort. Time was taken with a stop watch to the nearest 1/10 s. The best out of two trials (i.e., minimal sprint time) with a five-minute rest between trials was used for data analysis.

### *1-kg ball push test (standing position)*

Muscular strength of the upper extremities was assessed using the 1-kg medicine-ball push. This test is part of further German physical fitness batteries (Bös, 2000; Bös et al., 2001; Bös et al., 2009). Participants were instructed to stand with both feet right behind a starting line in frontal erect position and to push bimanually the ball forward from the chest as hard as they could. Distance was taken with a measuring tape to the nearest centimeter. The best out of two trials (i.e., maximal distance) with a one-minute rest between trials was used for data analysis.





**Figure 6:** Schematic description of the ball push test (standing position). (a: starting position, b: countermovement of the trunk, c: push action).

### *Standing long jump test*

The standing long jump is frequently used in test batteries for assessing muscular power of the lower body in children (Bös, Schlenker et al. 2009, Espana-Romero et al. 2010, Eurofit 1983). Participants were instructed to stand with both feet right behind a starting line and to jump as far as possible. Subjects were allowed to use arm swing during the test. Two trials were performed with a one-minute rest between them. The best trial in terms of maximal distance from the starting line to the landing point at heel contact was used for data analysis. Measurements were taken to the nearest centimeter using a tape measure.



**Figure 7:** Schematic description of the standing long jump.

### *Stand-and-reach test*

See test instruction under 5.2.1 (study 1 and 2)

### *Star agility run*

See test instruction under 5.2.1 (study 1 and 2)

### *6-min run test*

The 6-min run test is a test for the assessment of aerobic cardiorespiratory fitness and used in previously published German physical fitness batteries (Bös 2000, Bös et al. 2001, Bös, Schlenker et al. 2009, Jouck 2008). The test was conducted on a 54-m track. On the command ‘ready-set-go’, participants started their run. Split time was given every minute. The maximal distance achieved in six minutes was used for data analysis.

## 5.2.3 Quality criteria of conducted physical fitness tests

Reported values for the reliability and validity of all physical fitness tests are summarized in Table 4. The 6- min run and 9-min run have been shown to be valid in school-aged children populations (Faude et al. 2004, Lawrenz & Stemper 2012, Paludo et al. 2012, Turley et al. 1994) (A. S. Jackson & Coleman 1976). Furthermore, both distance runs showed good test-retest reliability in these age groups with Intraclass Correlation Coefficients (ICC) of 0.83 to 0.89 for the 9-min run and 0.72 for the 6-min run (Erbaugh, 1990; Fjortoft et al., 2011; Turley et al., 1994). The 50-m sprint and 20-m sprint proved to be reliable with ICC’s of 0.71-0.88 in youth populations aged 7 to 14 (Dollman & Norton

2002, Fjortoft et al. 2011). Test-retest reliability of the 1-kg ball push test (standing position) and the star-agility run were examined in a pilot project resulting in ICC of 0.82 and 0.68, respectively (Schulz 2013). The standing long jump has been shown to be a reliable (ICC = 0.88; 8.6±0.3 years) and valid test (isometric strength:  $r = 0.77$ ; 6-17 years) (Castro-Pinero et al. 2010, Fjortoft et al. 2011). In 12-14 years-olds a  $r$ -value of 0.91 is reported for test-retest reliability of the triple hop test. (Moll et al. 2012). The stand-and-reach test was proved to be reliable ( $r = 0.94$ ) for the assessment of flexibility in 7- to 11-years-olds (Bös, Schlenker et al. 2009). For the kneeling version of the 1-kg ball push test no reliability values are reported.

**Table 4:** Reported values of reliability and validity for the physical fitness tests included in the present thesis.

	reliability				validity					
	test specific	value	Age (years)	N (F)	[R]	type: criteria	value	Age (years)	N (F)	[R]
9-min run (m)	conducted outside on a 220-yard field	$R = 0.89$ (M: 0.89; F: 0.90)	8.9±0.6	48 (25)	[1]	rel. VO2 peak (cycle ergometer test)	$r = 0.62$ to $0.64$ (M: 0.65-0.71); (F: 0.48-0.56);	7-10	49 (25)	[11]
9-min run (m)	conducted outside on a 50-yard <sup>[2]</sup> and 400-m field <sup>[3]</sup>	$R = 0.83$ (M: x; F: x)	8.3±1.0	26 (13)	[2]	rel. VO2 peak (treadmill test)	$r = 0.64$ (M: 0.59; F: 0.43)	10-12	115 (54)	[3]
6-min run (m)	conducted inside on a 54-m field	$r = 0.92$ (M: x; F: x)	7-11	45 (x)	[4]	rel. VO2 peak (treadmill test)	$r = 0.69$ (M: 0.80; F: 0.68)	9-11	25 (13)	[5]
6-min run (m)	conducted inside on a 54-m field	$R = 0.72$ (M: x; F: x)	8.6±0.3	24 (x)	[6]	rel. PWCI70 and $P_{max}$ (treadmill test)	both: $r = 0.87$ (M: x; F: x)	11-13	30 (15)	[7]
1-kg ball push (m) – single arm, kneeling	/	/	/	/	/	/	/	/	/	/
1-kg ball push (cm)	/	$R = 0.82$ (M: x; F: x)	8-10	73 (39)	[8]	estimation of performance (ranking) by PE-teacher	$r = 0.46$ (M: x; F: x)	6-10	108	[9]
triple-hop (m)	conducted with the ‘jumping leg’	$r = 0.91$ (M: x; F: x) <sup>1</sup>	12-14	29 (11)	[10]	long jump-performance in competition	$r = 0.74$ to $0.96$	14	22 (0)	[10]
standing long jump (cm)	/	$R = 0.94$ (M: x; F: x)	8.5±1.7	363 (168)	[12]	1 RM leg extension test	$r = 0.40$ ; SLJ x weight: $r = 0.79$	8.5±1.7	363 (168)	[12]
standing long jump (cm)	/	$R = 0.88$ (M: x; F: x)	8.6±0.3	24 (x)	[6]	isometric strength; performance on SJ, CMJ, and VJ	$r = 0.77$ $r = 0.81$ to $0.91$	6-17	94 (45)	[11]

*Continued*

Table 4: –Continued

	reliability				validity					
	test specific	value	Age (years)	N (F)	[R]	type: criteria	value	Age (years)	N (F)	[R]
star agility run	/	$R = 0.68$ (M:0.72; F: 0.65)	8-10	73 (39)	[8]	/	/	/	/	/
50-m sprint (s)		$r = 0.93$	12-14	29 (11)	[10]	100-m run performance in competition	$r = 0.74$ to 0.96	14	22 (0)	[10]
50-m sprint (s)		$R = 0.88$	10-11	95 (x)	[13]	/	/	/	/	/
20-m sprint (s)		$r = 0.90$	7-11	45 (x)	[4]	estimation of PF by PE-teacher	$r = 0.73$ (M: 0.73; F: 0.72)	7-11	48 (19)	[4]
20-m sprint (s)	/	$R = 0.71$	8.6±0.3	24 (x)	[6]	/	/	/	/	/
stand and reach (cm)		$r = 0.94$	7-11	45 (x)	[4]	estimation of PF by PE-teacher	$r = 0.23$ (M: 0.22; F: 0.24)	7-11	48 (19)	[4]

Notes: F = Female; M = Male; [R] = Reference;  $R$  = Intraclass correlation coefficient;  $r$  = coefficient of correlation (by *Spearman* or *Pearson*); x = not reported; rel. = relative (for body mass); PF = Physical Fitness; PE = physical education; SJ = Squat Jump, CMJ = Counter Movement Jump, VJ = Vertical Jump; <sup>1</sup>Turley et al. (1994) (stated range of validity values relates to authors' reported values of Test- and Re-Test run); <sup>2</sup>Erbaugh (1990); <sup>3</sup>Paludo et al. (2012); <sup>4</sup>Bös et al. (2009); <sup>5</sup>Lawrenz & Stemper (2012) (no randomized sample, all students participated in a sports club); <sup>6</sup>Fjortoft et al. (2011); <sup>7</sup>Faude et al. (2004); <sup>8</sup>Schulz (2013); <sup>9</sup>Bös (2000); <sup>10</sup>Moll et al. (2012); <sup>11</sup>Castro-Piñero et al. (2010); <sup>12</sup>Fernandez-Santos et al. (2014); <sup>13</sup>Dollman et al. (2002).

### 5.3 Assessment of modifying factors on physical fitness

#### 5.3.1 Anthropometry

Study 1 and study 2 included annually measurements of body height and body mass. The measurements were carried out prior to physical fitness testing.

Body height was measured without shoes to the nearest 0.5 cm with a wall-mounted stadiometer (Seca, Basel, Switzerland). Body mass was determined in light clothing and without shoes to the nearest 100 g with an electronic scale (Bodymaster vision BM-210, Rowenta, France). Body mass index (BMI) was calculated using body mass divided by height squared ( $\text{kg/m}^2$ ).

#### 5.3.2 Living area

For study 2, information of children's area of residence was selected. Information was retrieved by a parental questionnaire that was sent home annually (i.e., four times). Area of residence was denoted as living area and classified in *urban* and *rural*. Classification was determined according to the number of inhabitants; i.e., communities of  $> 10,000$  inhabitants were defined as urban and communities of  $\leq 10,000$  inhabitants as rural areas. This classification was made according to the federal statistics report (MIL 2009) in which the cut-off value of inhabitants is associated with the criterion "facilities for covering the upmarket demand for residents" (e. g. medical care, school, supermarket, cinema etc.)".

#### 5.3.3 sports club participation & organized sports participation

For study 2, information of child's actual status of sports club membership (yes or no option) was provided by a parental questionnaire that was sent home annually (i.e., four times). The annual information of child's active membership was used to define sports club participation in accordance to the longitudinal study approach. Specifically, children that were continuously active member of a sports over the 4-year study period ('yes'-cohort) were compared to children that annually stated to be no active member of a sports club (i.e., 'yes'-cohort).

For study 3, children were questioned concerning their participation in sports clubs and in extra-curricular physical education classes by the physical education teacher. Organized sports participation was defined as actively participating in sports clubs and/or in extra-curricular physical education classes at least once a week (Yes or No option for both forms of sports participation). Children who actively participated in at least one out of the two given forms of sports participation were classified as 'organized sports participation'.

#### 5.3.4 Socioeconomic status

'Socioeconomic status (SES) of children' in study 3 was indirectly assessed by the use of SES of the community in which the school is located that children attending.

SES was determined for each of the 419 communities of the federal state Brandenburg, Germany. For this purpose, statistics from the Federal Employment Agency (Germany) and the Geomarketing-community Acxiom® (Germany) were used (Acxiom 2011). Factors for defining SES were (a) percentage of population with a university degree, (b) monthly average household income, and (c) percentage of recipients of basic security benefits for job seekers. In a first step, each of the three factors was rated on a five unit scale, with 5 points indicating best parameter value and 1 point worst parameter value. More specifically, percentage of population with a university degree:  $18.5 \leq \% \leq 43.2 = 5$  points,  $12.4 \leq \% \leq 18.3 = 4$  points, [...],  $0.1 \leq \% \leq 5.7 = 1$  point; monthly average household income:  $3,196 \leq \text{€} \leq 4,491 = 5$  points,  $2,757 \leq \text{€} \leq 3,068 = 4$  points, [...],  $1,871 \leq \text{€} \leq 2,422 = 1$  point; percentage of recipients of basic security benefits for job seekers (per 1,000 inhabitants):  $1.8 \leq \% \leq 7.4 = 5$  points,  $7.5 \leq \% \leq 10.3 = 4$  points, [...],  $18.4 \leq \% \leq 34.4 = 1$  point. Afterwards, items were averaged and mean values were divided in tertiles resulting in three equally sized groups representing communities with high ( $n = 136$ ), middle ( $n = 142$ ), and low ( $n = 141$ ) SES.

## 6. Studies

### 6.1 Study 1 – Physical fitness percentiles

*Publication title:*

**Physical fitness percentiles of children aged 9-12 years: findings from a longitudinal study**

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*Reference:*

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### 6.1.1 Abstract

Generating percentile values is helpful for the identification of children with specific fitness characteristics (i.e., low or high fitness level) to set appropriate fitness goals (i.e., fitness/health promotion and/or long-term youth athlete development). Thus, the aim of this longitudinal study was to assess physical fitness development in healthy children aged 9-12 years and to compute sex- and age-specific percentile values. Two-hundred and forty children (88 girls, 152 boys) participated in this study and were tested for their physical fitness. Physical fitness was assessed using the 50-m sprint test (i.e., speed), the 1-kg ball push test, the triple hop test (i.e., upper- and lower- extremity muscular power), the stand-and-reach test (i.e., flexibility), the star run test (i.e., agility), and the 9-min run test (i.e., endurance). Age- and sex-specific percentile values (i.e., P10 to P90) were generated using the Lambda, Mu, and Sigma method. Adjusted (for change in body mass, height, and baseline performance) age- and sex-differences as well as the interactions thereof were expressed by calculating effect sizes (Cohen's  $d$ ). Significant main effects of Age were detected for all physical fitness tests ( $d = 0.40$ - $1.34$ ), whereas significant main effects of Sex were found for upper-extremity muscular power ( $d = 0.55$ ), flexibility ( $d = 0.81$ ), agility ( $d = 0.44$ ), and endurance ( $d = 0.32$ ) only. Further, significant Sex by Age interactions were observed for upper-extremity muscular power ( $d = 0.36$ ), flexibility ( $d = 0.61$ ), and agility ( $d = 0.27$ ) in favor of girls. Both, linear and curvilinear shaped curves were found for percentile values across the fitness tests. Accelerated (curvilinear) improvements were observed for upper-extremity muscular power (boys: 10-11 yrs; girls: 9-11 yrs), agility (boys: 9-10 yrs; girls: 9-11 yrs), and endurance (boys: 9-10 yrs; girls: 9-10 yrs). Tabulated percentiles for the 9-min run test indicated that running distances between 1,407-1,507 m, 1,479-1,597 m, 1,423-1,654 m, and 1,433-1,666 m in 9- to 12-year-old boys and 1,262-1,362 m, 1,329-1,434 m, 1,392-1,501 m, and 1,415-1,526 m in 9- to 12-year-old girls correspond to a "medium fitness level (i.e., P40 to P60). The observed differences in physical fitness development between boys and girls illustrate that age- and sex-specific maturational processes might have an impact on the fitness status of healthy children. Our statistical analyses revealed linear (e.g., lower-extremity muscular power) and curvilinear (e.g., agility) models of fitness improvement with age which is indicative of timed and capacity-specific fitness development pattern during childhood. Lastly, the provided age- and sex-specific percentile values can be used for talent identification and rating/grading of motor performance in children.



### 6.1.2 Introduction

Children's health and well-being is highly correlated with their physical fitness. Recently published studies indicate that low levels of cardiorespiratory fitness (i.e., 20-m-shuttle-run test) are associated with an elevated risk of developing adverse physiological events (e.g., unbalanced body mass index, waist circumference, systolic blood pressure, plasma glucose, lipoprotein cholesterol, insulin resistance) in students aged 7-12 years (Llorente-Cantarero et al. 2012a; Llorente-Cantarero et al. 2012b).

Physical fitness is usually determined in school-aged children using health-related physical fitness batteries (i.e., field tests). Compared to more sophisticated laboratory-based test equipment, field tests are easy-to-administer, involve minimal equipment and personnel, demonstrate good validity and reliability (Safrit 1990), and a large number of subjects can be tested in a relatively small amount of time. Normative data derived from field tests have previously been used to identify subjects for health/talent promotion or to provide current objective recommendations for the assessment of physical fitness during physical education.

A number of studies provided percentile values in children and detected significant better performances for older as compared to younger children in nearly all physical fitness test items (Castro-Pinero et al. 2009, Catley & Tomkinson 2013, Lundgren et al. 2011, Santos et al. 2014). The same studies likewise observed sex differences for proxies of endurance, isometric voluntary muscle strength, muscular power, muscle endurance, and speed in favor of boys (Castro-Pineiro et al. 2011, Castro-Pinero et al. 2009, Catley & Tomkinson 2013, Roriz De Oliveira et al. 2014, Santos et al. 2014). For example, Castro-Pinero et al. (2009) reported better performances in measures of muscular power (i.e., standing broad jump, vertical jump, throw ball) and muscle endurance (i.e., bent arm hang, pull ups) in boys as compared to girls aged 8-9, 10-11, and 12-13 years. Further, Santos et al. (2014) reported that 10- to 12-year-old boys outperformed girls of the same age in endurance (i.e., 20-m shuttle run) and muscle endurance (i.e., curl-ups, push-ups), while girls performed better in flexibility (i.e., modified back-saver sit-and-reach) than boys. Finally, 6- to 10-year-old boys achieved better results in speed (i.e., 50-yard dash), isometric voluntary muscle strength (i.e., HGS-test), muscular power (i.e., SLJ-test), agility (i.e., 4 x 10-m shuttle run), and endurance (i.e., 1-mile run/walk) (Roriz De Oliveira et al. 2014). Of note, girls showed better performances in the flexibility test (i.e., sit-and-reach). Findings from these studies are helpful for the identification of individuals with specific physical fitness characteristics (e.g., talent identification) and the quantification of performance differences between ages and sex. However, the above mentioned studies are methodologically flawed due to their cross-sectional nature. More precisely, percentile values were computed using a cross-sectional approach (i.e., between-subject comparisons of different age groups). This is a major limitation because such an approach does not allow to deduce true physical fitness development within subjects (i.e., individual changes in timing and tempo of growth and maturation) over time. In fact, Andersen and colleagues (Andersen et al. 1976) examined 8-year-old children during a period of four years for their cardiorespiratory fitness (i.e., oxygen uptake during bicycle ergometry). The longitudinal

data was compared with cross-sectional data obtained from 8- to 14-year-olds. The authors observed considerably higher fitness levels in children that were longitudinally followed as opposed to those children who were assessed in a cross-sectional analysis.

Based on these findings, it is essential to use longitudinal data of the same individuals if the goal is to provide percentile values and to determine age- and sex-related differences in fitness development. Thus, the aim of the present study was to longitudinally assess physical fitness in a large sample of 268 healthy boys and girls from age 9 to 12 years. More specifically, age- and sex-specific differences in physical fitness (i.e., agility, endurance, flexibility, muscular power, speed) were quantified and percentile values computed. It is hypothesized that physical fitness improves from age 9-12 and that sex-specific differences occur over time.

### 6.1.3 Methods

A longitudinal approach was used to test changes in physical fitness in 9- to 12-year-old children over time (i.e., from classes 3 to 6). The participating children attended 27 public primary schools in the federal state Brandenburg (Germany). Each of the four testing periods over the four year study period lasted four weeks (always from March to April). The study was approved by the Ministry of Education, Youth and Sport of the federal state Brandenburg. Parents or legal representatives of each child provided written informed consent that included information regarding child's birthdate. Chronological age with two decimals was calculated for each child as the difference between test date and birthdate. Age groups were categorized and classified as a whole year (i.e., 9.00-9.99 years  $\triangleq$  9 years, etc.). The study was conducted according to the latest version of the declaration of Helsinki. Four hundred and seventy students who attended grade three at the start of the study were invited to participate in the study. Informed consent and valid data were obtained from 364 children (146 girls, 218 boys) over the four year period. The age range of the enrolled children at the baseline tests (i.e., grade three) spanned from seven years (one girl), over eight years (48 girls; 53 boys), nine years (88 girls; 152 boys), ten years (nine girls; ten boys) up to eleven years (three boys). Due to the fact that computing percentile values in a longitudinal approach is limited to a single age group, only children aged nine (88 girls; 152 boys) were considered for further analysis.

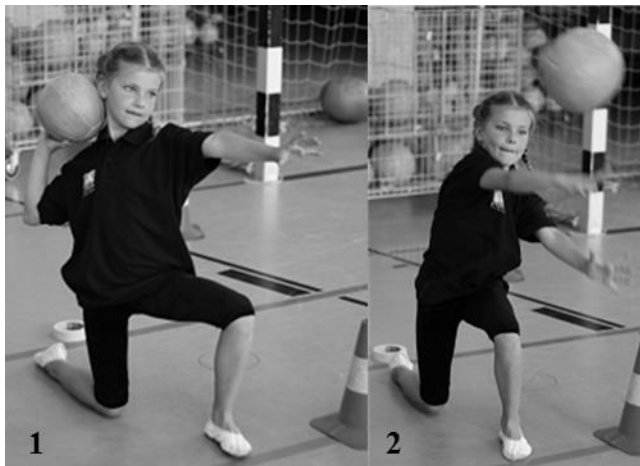
#### *Anthropometry*

Prior to physical fitness testing, body height was measured without shoes to the nearest 0.5 cm with a wall-mounted stadiometer (Seca, Basel, Switzerland). In addition, body mass was determined in light clothing and without shoes to the nearest 100 g with an electronic scale (Bodymaster vision BM-210, Rowenta, France). Body mass index (BMI) was calculated using body mass divided by height squared ( $\text{kg}/\text{m}^2$ ).

#### *Physical fitness tests*

Physical fitness was determined using six different test items from motor fitness test batteries of Bös (2009) and Stark (2000). The same cohort was followed over the four year period and the children were tested in class 3 and in classes 4, 5, and 6. The tests included

the following items: 50-m sprint test (speed), 1-kg ball push test (upper-extremity muscular power), triple hop test (lower-extremity muscular power), stand-and-reach test (flexibility), star agility run test (agility), and 9-min run test (endurance). All tests were performed in the respective school gyms during official physical education classes using standardized test protocols. Furthermore, figures and illustrations were used to explain important characteristics for each test item (for an example see Figure 8). A counter-balanced sequence of measurements was applied. Before testing, all students conducted a 10-minutes standardized warm-up program consisting of light running followed by different conditioning activities (e.g., side steps, backwards run, skipping, submaximal plyometric exercises, and short distance sprints).



**Figure 8:** Schematic description of the ball push test (1: starting position, 2: push action).

#### 50-m sprint test

Speed performance was assessed in a stationary starting position (Stark 2000). Participants were instructed to stand in frontal erect posture with one foot right behind the starting line. Students started the first of two trials on the command ‘ready-set-go’ and accelerated at maximum effort. Time was taken with a stop watch to the nearest 1/10 s. The best trial (i.e., least running time) was used for further data analysis. The 50-m sprint proved to be reliable with an intraclass correlation coefficient (ICC) of 0.88 for the assessment of speed in 10- to 11-years-olds (Dollman & Norton 2002).

#### Ball push test

Muscular power of the upper extremities was assessed using the 1-kg medicine ball push test (Figure 8) (Stark 2000). The test was performed with the single left and right arm. For the right-handed push, participants set the right knee on the floor with a 90° angle between lower leg and thigh whereas the foot of the left leg stood behind the starting line with a 90° angle between lower leg and thigh of the left leg. The right hand held the ball at the neck. The extended left arm pointed forward at eye level (i.e., pushing direction). For the left-handed push the starting position for arms and legs changed, respectively (i.e., right arm pointed forward, left knee on the floor, and right foot at the starting line). In this frontal erect position, participants had to counter-rotate the trunk and push the ball as far as possible. The ball pushing distance was taken using a measuring tape to the nearest 25

centimeters (i.e., quarter of meter). Two trials were performed for each arm with a one minute rest before changing the pushing arm. The best trial in terms of maximal distance for each arm was summed and used for further data analysis.

#### Triple hop test

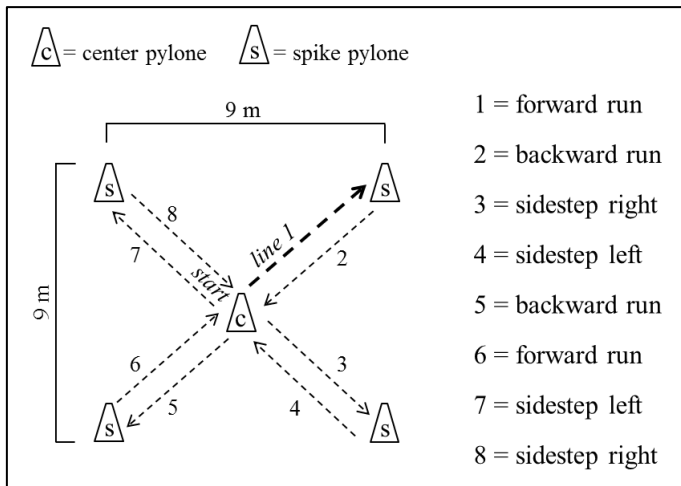
Lower-extremity muscular power was tested using the triple hop test (Stark 2000). Participants were instructed to stand with one foot right behind the starting line and to jump three times with the same leg as far as possible and to land on both feet. Subjects were allowed to use arm swing during the tests. Two trials were performed for each leg with a one minute rest between trials. The best trial in terms of maximal distance from the starting line to the landing point at heel contact for each leg was added and used for statistical analysis. Measurements were taken to the nearest centimeter using a tape measure. The triple hop test is a reliable test ( $r = 0.91$ ) for the assessment of lower-extremity muscular power 12- to 14-years-olds (Moll et al., 2012).

#### Stand-and-reach test

Flexibility was tested using the stand- and-reach test (Bös 2009). Subjects were instructed to begin the test in a barefoot standing position on an elevated platform with feet together. They were asked to bend over using their maximal range of motion during expiration. During the test, knees, arms, and fingers were fully extended for at least two seconds. A tape measure was attached to the platform with 100 cm corresponding to the upper level of the platform. Values above 100 cm indicate that the person was able to reach beyond the toes (i.e., good flexibility). Values below 100 cm indicate that the person was not able to reach the toes (i.e., limited flexibility). The best out of two trials (i.e., maximal reach distance) with a one minute rest between trials was used for further data analysis. The stand-and-reach test is a reliable test ( $r = 0.94$ ) for the assessment of flexibility in 7- to 11-years-olds (Bös, 2009).

#### Star agility run test

Agility was tested using the star agility run test (Stark 2000). Participants were instructed to run in different running techniques (e.g., forward, backward, side steps) from the center to the edge and back of a 9 x 9-m star-shaped field with four spikes (Figure 9). The spikes and the center of the field were each marked with pylons (height: 30 cm). Starting at the center of the field, the participants had to run forward to spike 1 (line 1) and backward to the center (line 2). From the center, they turned to the right side and side-stepped to spike 2 (line 3), turned to the left side and side-stepped back to the center (line 4). Upon reaching the center, students turned backward and ran to spike 3 (line 5) and forward to the center (line 6). Finally, they turned to the left side and side-stepped to spike 4 (line 7), turned to the right side and side-stepped back to the center (line 8). During the test, subjects had to touch the top of the pylons at each respective spike and when traversing the center position. Time was taken with a stop watch to the nearest 1/10 of a second. Subjects performed one practice trial and thereafter two test trials with a five minute rest in between. The best trial (i.e., least running time) was used for further data analysis. The star agility run test proved to be reliable with an ICC of 0.68 in 8- to 10-years-olds (Schulz, 2013).



**Figure 9:** Schematic description of the star agility run test.

### 9-min run test

The 9-min run test is a test for the assessment of aerobic capacity (Stark 2000). Participants started their run on the command 'ready-set-go'. Split time was given every minute. The maximal distance achieved during the nine minute run was used for further data analysis. Excellent reliability has been reported for the 9-min run test with an ICC of 0.83 in 6- to 10-year-olds (Erbaugh 1990).

### Statistical analyses

Anthropometric and physical fitness test data were grouped by sex and age. Mean values and standard deviations were calculated for each group. Development of anthropometry and physical fitness over time was analyzed using a 2 (Sex: boys, girls) x 4 (Age: 9, 10, 11, 12 years) analysis of covariance (ANCOVA) with repeated measures on Age. Due to the fact that growth and maturation may have an impact on physical fitness level and its development in youth (Malina et al. 2004), the following covariates were included in our ANCOVA model: (1) test-specific physical fitness performance at baseline, (2) change in body mass, and (3) change in body height. Changes in body mass and height were calculated as differences between measurements performed at age 9 and 12. When 'Sex by Age' interactions reached the level of significance, group-specific post-hoc tests (i.e., paired t-tests) were conducted to identify the comparisons that were statistically significant. Additionally, Cohen's  $d$  was calculated. According to Cohen (1988),  $0.20 \leq d \leq 0.49$  indicates a small,  $0.50 \leq d \leq 0.79$  indicates a medium, and  $d \geq 0.80$  indicates a large effect size. The significance level was set at  $p < .05$ . All analyses were performed using Statistical Package for the Social Sciences (SPSS) version 22.0.

Further, normative sex-specific centile values were generated using LMS chartmaker Pro (v2.54, The Institute of Child Health, London) software. More precisely, the Lambda, Mu, and Sigma (LMS) method provided by Cole (1990) were applied next to statistical procedures for model fitting and checking (Cole & Green 1992, Pan & Cole 2004, 2005). For each of the six physical fitness tests, centile curves were calculated which express the distribution of the respective performances as it changes over time. Performance changes were plotted according to age and illustrated using three curves

representing the skewness (L for Lambda), the median (M for Mu), and the coefficient of variation (S for Sigma). The skewness expresses the power in the Box-Cox-Transformation which normalizes the data distribution by variance stabilization. Using penalized likelihood with Generalised Akaike Information Criterion (GAIC) the three curves were fitted as cubic splines by nonlinear regression. The extent of curve-smoothing required was expressed in terms of equivalent degrees of freedom (edf) of each L, M, and S curve as measure of its complexity (Pan & Cole 2005). System's requirement of curve smoothing included an alternative transformation of original age (o) scale, denoted as rescaled age (r), too. Rescaled age is an empirical transformation based on the shape of the fitted M curve. In a last step, the goodness of model fit was checked by Q-Tests for fit (Pan & Cole 2004) and, if necessary, improved by adjusting edf of L, M, and S curve. All centile-analyses were performed for boys and girls, separately and expressed as tabulated percentiles (P) from P<sub>10</sub> to P<sub>90</sub> and as smoothed centile curves showing P<sub>10</sub>, P<sub>50</sub>, and P<sub>90</sub>.

#### 6.1.4 Results

Anthropometric and physical fitness test data of the study sample sorted by Sex and Age are presented in Table 5. Significant main effects of Age but not of Sex were found for body mass ( $p < .001$ ,  $d = 4.21$ ), body height ( $p = <.001$ ,  $d = 6.88$ ), and BMI ( $p = <.001$ ,  $d = 1.91$ ). Furthermore, a statistically significant interaction effect of Sex by Age was detected for body height ( $F_{[1, 238]} = 10.3$ ,  $p < .001$ ,  $d = 0.42$ ). Post-hoc analyses indicated a significantly larger somatic growth in girls (9-12 years:  $d = 2.50$ ) than in boys (9-12 years:  $d = 2.03$ ).

**Table 5.** Development of anthropometry and physical fitness in 9 to 12 years old boys (n = 152) and girls (n = 88).

	9 years		10 years		11 years		12 years		Main/interaction effect: <i>p</i> -value ( <i>d</i> )		
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Sex	Age	Sex by Age
body mass (kg)	33.1 (6.1)	31.7 (5.4)	37.3 (7.3)	36.0 (7.0)	42.6 (9.1)	41.0 (8.8)	47.6 (10.0)	46.3 (10.1)	.183 (0.17)	<.001 (4.21)	.873 (0.04)
body height (cm)	140.5 (6.2)	138.1 (5.8)	144.8 (6.7)	142.3 (6.2)	150.8 (7.1)	150.0 (6.9)	156.8 (8.0)	155.9 (7.2)	.066 (0.24)	<.001 (6.88)	<.001 (0.42)
BMI (kg/m <sup>2</sup> )	16.7 (2.5)	16.6 (2.3)	17.7 (2.7)	17.7 (2.7)	18.6 (3.1)	18.1 (3.0)	19.2 (3.1)	18.9 (3.3)	.514 (0.09)	<.001 (1.91)	.101 (0.19)
50-m sprint (s)	9.6 (0.8)	9.8 (0.9)	9.2 (0.9)	9.5 (0.9)	8.9 (0.8)	9.0 (0.8)	8.7 (0.8)	8.8 (0.8)	.314 (0.13)	<.001 (0.69)	.324 (0.14)
ball push (m)	7.91 (1.41)	6.40 (1.30)	8.93 (1.51)	7.56 (1.26)	10.70 (1.92)	8.84 (1.60)	11.57 (2.31)	9.79 (1.71)	<.001 (0.55)	<.001 (0.40)	<.001 (0.36)
triple-hop (m)	7.65 (1.24)	7.26 (1.15)	8.44 (1.19)	8.04 (1.21)	9.17 (1.26)	8.83 (1.16)	9.78 (1.43)	9.37 (1.31)	.096 (0.22)	<.001 (0.67)	.114 (0.19)
stand-and-reach (cm)	96 (8)	100 (8)	96 (8)	101 (7)	95 (9)	103 (7)	96 (9)	104 (8)	<.001 (0.81)	<.001 (0.43)	<.001 (0.61)
star agility run (s)	23.2 (3.3)	23.9 (3.0)	21.0 (2.1)	22.0 (2.1)	19.6 (1.9)	20.3 (1.8)	19.0 (1.9)	19.5 (1.7)	.001 (0.44)	<.001 (1.34)	.004 (0.27)
9-min run (m)	1471 (203)	1319 (204)	1569 (269)	1417 (225)	1606 (248)	1467 (201)	1598 (258)	1469 (218)	.014 (0.32)	<.001 (0.79)	.113 (0.18)

Notes: Values are means (± SD); <sup>1</sup>Results of the Sex by Age ANCOVA (covariate: baseline performance, change in body mass and height) with repeated measures on Age; *d* = effect size Cohen's *d*; BMI = Body Mass Index.

*Physical fitness differences by age and sex*

Significant main effects of Age were found for all physical fitness tests (all  $p < .001$ ,  $d = 0.43$ - $1.34$ ). Additionally, the main effect of Sex was significant for the ball push test ( $F_{[1, 238]} = 17.9$ ,  $p < .001$ ,  $d = 0.55$ ), the stand-and-reach test ( $F_{[1, 238]} = 38.7$ ,  $p < .001$ ,  $d = 0.81$ ), the star agility run test ( $F_{[1, 238]} = 11.4$ ,  $p = .001$ ,  $d = 0.44$ ), and the 9-min run test ( $F_{[1, 238]} = 6.1$ ,  $p = .014$ ,  $d = 0.32$ ). Lastly, statistically significant interaction effects of Sex by Age (adjusted for change in body mass, height, and baseline performance) were detected for the ball push test ( $F_{[3, 714]} = 7.8$ ,  $p < .001$ ,  $d = 0.36$ ), the stand-and-reach test ( $F_{[3, 714]} = 21.9$ ,  $p < .001$ ,  $d = 0.61$ ), and the star agility run test ( $F_{[3, 714]} = 4.4$ ,  $p = .004$ ,  $d = 0.27$ ). Post-hoc analyses regarding performance changes from age 9 to 12 revealed larger improvements in girls than boys for the ball push test (girls:  $d = 2.19$ ; boys:  $d = 1.81$ ), the stand-and-reach test (girls:  $d = 0.55$ ; boys:  $d = 0.07$ ), and the star agility run test (girls:  $d = 1.65$ ; boys:  $d = 1.46$ ).

*Percentile curves by age and sex*

Smoothed age-specific percentiles (i.e., from  $P_{10}$  to  $P_{90}$ ) are presented in Table 6 for the 50-m sprint test, the 1-kg ball push test, and the triple hop test. Table 7 illustrates smoothed age-specific percentiles for the stand-and-reach test, the star agility run test, and the 9-min run test. For the same physical fitness items, smoothed LMS curves for 10<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentile are depicted in Figure 10. Our data indicate a linear improvement for proxies of speed (both sexes), lower-extremity muscular power (both sexes), and flexibility (girls only).—Curvilinear enhancements were found in boys and girls for measures of upper-extremity muscular power, agility, and endurance. For endurance, curvilinear pattern merged in a performance plateau at the age of 12 in both sexes. Notably, no performance development was observed for the stand-and-reach test in boys. Further, margins between  $P_{10}$ ,  $P_{50}$ , and  $P_{90}$  hardly changed over time for the 50-m sprint test in both sexes. The same pattern was found in girls for the triple hop test, the stand-and-reach test, and the 9-min run test. In contrast, margins between percentile curves decreased with advancing age for the star agility run test and increased for the ball push test in both sexes. In addition, an increase of margins between the 10<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentile was observed for the triple hop test and the 9-min run test in boys.



**Table 6:** Smoothed age- and sex-specific percentile values for the 50-m sprint (s), ball push test (m), and triple hop test (m).

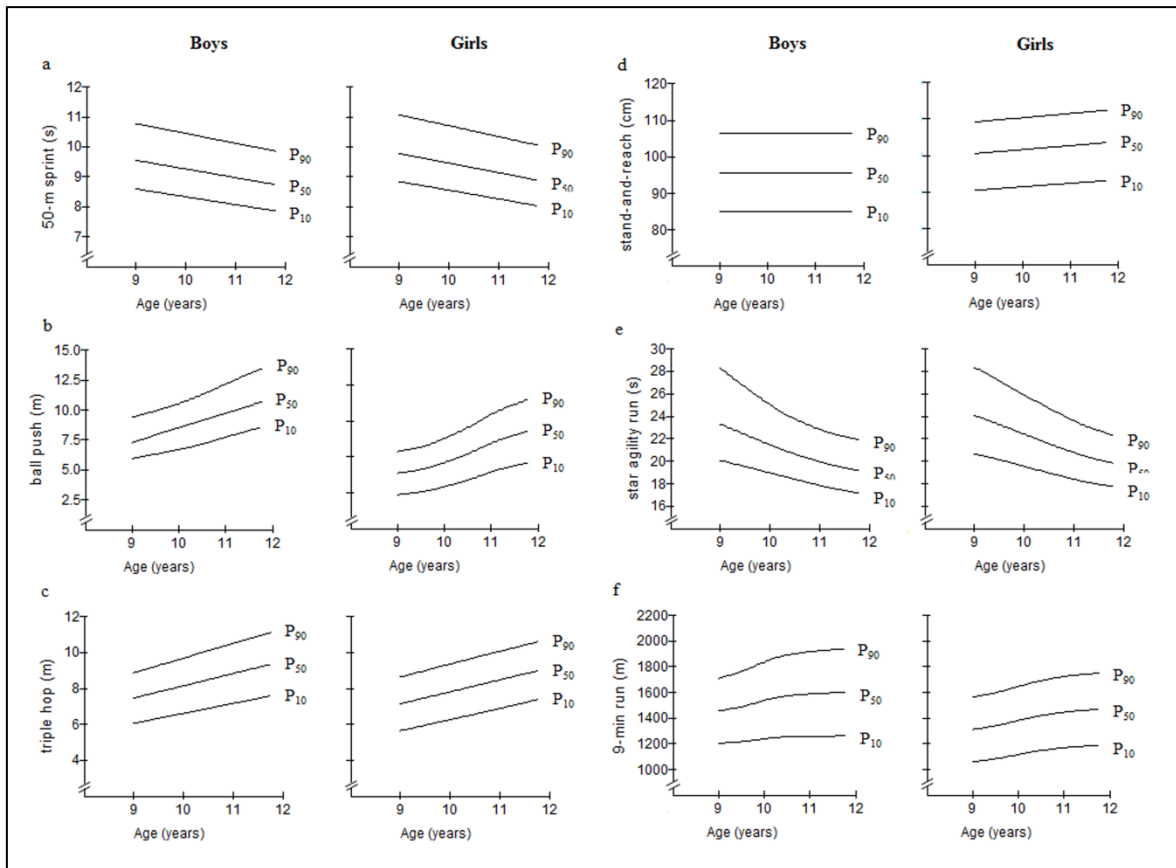
Age (yrs)	P <sub>10</sub>	P <sub>20</sub>	P <sub>30</sub>	P <sub>40</sub>	P <sub>50</sub>	P <sub>60</sub>	P <sub>70</sub>	P <sub>80</sub>	P <sub>90</sub>
50-m sprint (s)									
Boys <sup>[1/2/1o]</sup>									
9	8.6	9.0	9.1	9.3	9.5	9.8	10.0	10.3	10.8
10	8.3	8.7	8.9	9.1	9.3	9.5	9.7	10.0	10.4
11	8.1	8.5	8.6	8.8	9.0	9.2	9.4	9.7	10.1
12	7.8	8.2	8.3	8.5	8.7	8.9	9.1	9.4	9.8
Girls <sup>[1/2/1o]</sup>									
9	8.8	9.1	9.4	9.6	9.8	10.0	10.2	10.6	11.1
10	8.5	8.8	9.1	9.3	9.5	9.7	9.9	10.2	10.7
11	8.3	8.5	8.7	8.9	9.1	9.3	9.6	9.9	10.3
12	8.0	8.2	8.4	8.6	8.8	9.0	9.2	9.5	10.0
ball push test (m)									
Boys <sup>[4/2/1o]</sup>									
9	5.93	6.51	6.67	6.98	7.29	7.63	8.03	8.55	9.39
10	6.67	7.52	7.74	8.13	8.51	8.89	9.31	9.81	10.52
11	7.72	8.63	8.86	9.30	9.73	10.17	10.67	11.27	12.15
12	8.79	9.74	9.99	10.47	10.95	11.45	12.03	12.74	13.83
Girls <sup>[0/4/1r]</sup>									
9	4.85	5.37	5.74	6.06	6.35	6.65	6.97	7.34	7.86
10	5.42	5.99	6.41	6.76	7.09	7.42	7.78	8.19	8.77
11	6.45	7.13	7.63	8.05	8.44	8.84	9.26	9.75	10.44
12	7.23	7.99	8.55	9.02	9.46	9.91	10.38	10.93	11.70
triple hop test (m)									
Boys <sup>[0/2/1o]</sup>									
9	6.06	6.73	6.89	7.19	7.47	7.75	8.04	8.39	8.88
10	6.61	7.34	7.52	7.84	8.15	8.45	8.78	9.16	9.69
11	7.16	7.95	8.15	8.50	8.83	9.16	9.51	9.92	10.49
12	7.71	8.56	8.77	9.15	9.51	9.86	10.24	10.69	11.30
Girls <sup>[0/2/2o]</sup>									
9	5.65	6.16	6.53	6.85	7.14	7.44	7.75	8.12	8.63
10	6.26	6.79	7.17	7.50	7.81	8.11	8.44	8.82	9.36
11	6.89	7.43	7.82	8.16	8.47	8.79	9.12	9.52	10.06
12	7.53	8.08	8.48	8.82	9.14	9.46	9.80	10.20	10.75

*Notes.* P = percentile; in square parentheses: equivalent degrees of freedom (edf) for the chosen model of L/M/S method; L = skew; M = median; S = coefficient of variation; o = original age; r = rescaled age.

**Table 7:** Smoothed age- and sex-specific percentile values for the stand-and-reach test (cm), star agility run (s), and the 9-min run test (m).

Age (yrs)	P <sub>10</sub>	P <sub>20</sub>	P <sub>30</sub>	P <sub>40</sub>	P <sub>50</sub>	P <sub>60</sub>	P <sub>70</sub>	P <sub>80</sub>	P <sub>90</sub>
stand-and-reach (cm)									
Boys <sup>[1/2/1o]</sup>									
9	85	90	91	93	96	98	100	103	106
10	85	90	91	93	96	98	100	103	106
11	85	90	91	93	96	98	100	103	106
12	85	90	91	93	96	98	100	103	106
Girls <sup>[1/2/1o]</sup>									
9	91	94	97	99	101	102	104	106	109
10	91	95	98	100	102	103	105	108	110
11	92	96	99	101	103	105	106	109	112
12	93	97	100	102	104	106	108	110	113
star agility run (s)									
Boys <sup>[1/3/3r]</sup>									
9	20.1	21.4	21.8	22.5	23.3	24.1	25.0	26.3	28.3
10	19.0	20.0	20.3	20.9	21.4	22.0	22.7	23.6	25.0
11	17.8	18.8	19.0	19.5	19.9	20.4	21.0	21.7	22.8
12	17.0	17.9	18.1	18.6	19.0	19.5	20.0	20.7	21.7
Girls <sup>[1/3/2r]</sup>									
9	20.7	21.7	22.6	23.3	24.1	24.8	25.7	26.8	28.3
10	19.5	20.5	21.2	21.8	22.4	23.0	23.7	24.6	25.9
11	18.4	19.2	19.7	20.3	20.8	21.3	21.9	22.6	23.6
12	17.6	18.3	18.8	19.3	19.7	20.1	20.6	21.2	22.1
9-min run (m)									
Boys <sup>[0/2/1r]</sup>									
9	1205	1324	1354	1407	1457	1507	1561	1623	1710
10	1240	1381	1416	1479	1538	1597	1660	1734	1836
11	1259	1415	1454	1523	1588	1654	1723	1805	1918
12	1261	1421	1461	1533	1600	1666	1738	1822	1938
Girls <sup>[0/3/1r]</sup>									
9	1061	1147	1209	1262	1312	1362	1415	1477	1563
10	1117	1208	1273	1329	1381	1434	1490	1555	1646
11	1170	1265	1333	1392	1447	1501	1560	1629	1724
12	1189	1286	1355	1415	1471	1526	1586	1655	1752

*Notes.* P = percentile; in square parentheses: equivalent degrees of freedom (edf) for the chosen model of L/M/S method; L = skew; M = median; S = coefficient of variation; o = original age; r = rescaled age.



**Figure 10:** Smoothed LMS curves for the 10<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentiles of the (a) 50-m sprint test, (b) ball push test, (c) triple hop test, (d) stand-and-reach test, (e) star agility run test, and (f) 6-min run test in boys and girls from age 9 to 12 years.

### 6.1.5 Discussion

To the authors' knowledge, this is the first study that provides longitudinal data on age- and sex-specific physical fitness percentiles in healthy children aged 9-12 years. The major strength of the present longitudinal study as compared to cross-sectional studies is that individual changes in timing and tempo of growth and maturation are taken into account.

#### *Age and sex differences in physical fitness*

Initially, we hypothesized that physical fitness levels increase from age 9-12. Our findings confirm the first hypothesis because physical fitness significantly improved over the four year study period in males and females (except for flexibility in boys). Data from cross-sectional studies confirm our findings in as much as physical fitness enhancements were reported in groups of increasing age (Catley & Tomkinson 2013, Santos et al. 2014, Woll et al. 2011). For example, Woll et al. (2011) demonstrated higher performance levels (i.e., endurance, static/dynamic balance, lower-body muscular power, muscle endurance, coordination under time pressure) with age in 4- to 17-years-olds. Similar results are reported by Catley and Tomkinson (2013) who analyzed performances in health-related fitness tests (i.e., 1.6-km run, 20-m shuttle run, 50-m sprint, basketball throw, standing broad jump, push-ups, sit-ups, HGS-test) in 9- to 17-years-olds from 1985 up to 2009. Age-related differences in physical fitness are typically attributed to growth (i.e., increase in body size, body mass, and body dimensions) and maturation (i.e., somatic, skeletal, and sexual maturity) that occur during childhood and adolescence (Malina et al. 2004). Furthermore, no statistically significant improvements were detected for the stand-and-reach test in boys. This is in line with a cross-sectional study conducted by Castro-Pinero et al. (Castro-Pineiro et al., 2013) who tested flexibility in 6- to 17-years-olds. As a result, sit-and-reach test performance did not significantly improve in boys (Castro-Pineiro et al. 2013). Amongst other reasons, this can most likely be explained by maturational processes of joint structures and by an increase in muscle mass, particularly in boys (Malina et al., 2004).

Our study findings also confirm our second hypothesis in as much as we observed significant sex differences in physical fitness development over time. In fact, our results revealed that boys outperformed girls in the ball push test (medium effect size), the star agility run test (small effect size), and the 9-min run test (small effect size). In contrast, girls achieved higher values in the stand-and-reach test (large effect size). These results are in line with findings from cross-sectional studies (Castro-Pinero et al. 2009, De Miguel-Etayo et al. 2014, Roriz De Oliveira et al. 2014, Woll et al. 2011). In fact, Castro-Pinero et al. (2009) reported that boys aged 8-9, 10-11, and 12-13 achieved significantly better performances in the ball throw test compared to girls of the same age. The observed sex differences can most likely be attributed to a better ratio of strength relative to body mass in boys compared to girls, particularly in the upper limbs and trunk (Beunen & Thomis 2000). In addition, relative muscle strength of the upper limbs (i.e., normalized to muscle cross-sectional area) is already higher in boys as compared to girls during childhood (Van Praagh & Dore 2002). Further, Roriz De Oliveira et al. (2014) found significantly better agility (i.e., 4 x 10-m shuttle run test) in 6- to 10-year-old boys compared to girls. The

better agility performance in boys as in girls can be explained by their higher absolute and relative (i.e., in relation to body mass and fat-free mass) anaerobic power values obtained during the 30-s Wingate Anaerobic Test (Martin & Malina 1998). In addition, De Miguel-Etayo and colleagues (2014) reported significantly better endurance (i.e., 20-m shuttle run test) in 6- to 9-years-old boys as compared to girls. The observed sex differences in endurance might be explained by a higher maximal aerobic capacity in boys. For example, longitudinal analyses in children aged 8-18 revealed that before the age of 10-12 years, girls' average  $\text{VO}_2\text{max}$  reaches about 85-90% of that of boys. Likewise, sex differences exist when body mass is taken into account (90-95% of male mean values) (Malina et al. 2004). Finally, higher flexibility scores (i.e., stand-and-reach test, back-saver sit-and-reach test) were reported for girls as compared to boys (De Miguel-Etayo et al. 2014, Woll et al. 2011). This might be explained by a higher percentage of body fat and a lower percentage of muscle mass due to higher circulating levels of estrogens or lower circulating levels of androgens in girls compared to boys. As a result, tissue density is lower in girls which may result in better flexibility (Beunen & Malina 1988, Malina et al. 2004). Besides these physiological factors, behavioral aspects may also account for the observed sex differences in flexibility during childhood. For example, Haywood and Getchell (2009) argued that stretching exercises are socially more acceptable for girls than vigorous (muscle strengthening) exercises and that a higher proportion of girls participates in gymnastics and dance as compared to boys.

In the present study, the observed improvements in physical fitness with advancing age occurred at different rates which are indicated by linear versus curvilinear percentile models. More specifically, linear improvements were found for proxies of speed (both sexes), lower-extremity muscular power (both sexes), and flexibility (in girls). In contrast, curvilinear models are effective for both sexes regarding measures of upper-extremity muscular power, agility, and endurance. Moreover, our adjusted analyses (i.e., changes in body mass, height, and baseline performance) revealed significant Sex by Age interaction effects. These were found for the ball push test, the stand-and-reach test, and the star agility run test. Post-hoc analyses revealed that performance progression for the ball push test and the star agility run test was slightly larger in girls compared to boys but reached similar effect sizes (i.e., large effect). With regards to the stand-and-reach test, performance development was substantially faster in girls than in boys as indicated by a medium vs. small effect size, respectively.

These findings may indicate a timed and capacity-specific development pattern during childhood as described by the biological concept of "critical or sensitive maturational periods" (Viru et al. 1999). Critical periods can be characterized as periods during which ontogenetic development reaches a qualitatively new level that provides opportunities for the further improvement of an organ, tissue, and/or physiological functions (Viru et al. 1999). Sex-specific critical periods of accelerated (i.e., curvilinear) performance improvements have been reported for several proxies of physical fitness (except agility) (Lloyd & Oliver 2012, Viru et al. 1999, Viru et al. 1998). Furthermore, accelerated gains in muscle strength were detected for different ages depending on the investigated strength capacity (e.g., maximal voluntary isometric strength, muscular

power). More specifically, intense improvements in muscular power (boys: 7-9 years and 13-16 years; girls: 6-8 years and 11-12 years) occur earlier than those in maximal voluntary isometric strength (boys: 14-16 years; girls: 12-13 years) (Virus et al. 1998). With respect to upper-extremity muscular power (i.e., ball push test), we found the highest annual gains between the ages of 9-11 years in girls (17-18%) and 10-11 years in boys (20%). The present study provides new in-depth insight in the development of agility. Accelerated improvements were found for the star agility run test in girls aged 9-11 (8%) and boys aged 9-10 (10%). In addition, we observed an accelerated improvement in aerobic endurance at the age of 9-10 in girls (7%) and boys (7%). This is in line with previous results of Andersen and colleagues who assessed aerobic endurance in a longitudinal approach in 8- to 12-year-old children (Andersen et al. 1976). As a result the largest performance gains (8-10%) were reported for girls and boys aged 9-10 years.

Of note, children's performance development in physical fitness is affected by somatic growth. Sex-specific changes in parameters like body height and mass particularly occur from age 9 to 12 (Malina et al. 2004). More specifically, a significantly larger growth in body height has been reported for girls as indicated in growth velocity curves (Malina et al. 2004). For example, Tanner et al. (Tanner et al. 1966) showed an earlier beginning of an accelerated height gain (i.e., cm/year) in girls (10 years) as compared to boys (12 years). Our data are in accordance with the literature because the statistical analyses revealed a significantly larger growth of body height in girls compared to boys. This may in fact explain the observed faster performance development in the ball push test, the star agility run test, and the stand-and-reach test in girls.

#### *Physical fitness percentiles*

To the authors' knowledge, this is the first study that reports physical fitness percentiles from longitudinal data. More specifically, the present study provided age- and sex-specific percentile values obtained from the same children over a four year study period (i.e., from 9-12 years of age). The reported percentile values are of particular importance for educational (e.g., schools), athletic (e.g., talent identification), and healthcare settings (e.g., sports/fitness clubs). Data from this longitudinal study can be used to grade motor performance and motor performance development of children aged 9-12 during physical education. With regard to long-term athlete development and the identification of talents, the age range of 9-12 years is an important stage (i.e., "Learn to Train stage") during which children are supposed to take up general sporting skills that build a strong foundation for subsequent stages during long-term athlete development (i.e., "Train to Train", "Train to Compete", and "Train to Win" stage) (Balyi et al. 2013). Our findings of percentile values may help to detect high fit children at a certain point and/or over time. More specifically, children performing above the 80<sup>th</sup> percentile can be classified as 'very high fit'. Sports organizations/associations and sports clubs should offer multifaceted and appealing sport programs to the previously identified children that further their athletic development to finally become a high performance athlete.

The identification of low performing children is as important as the identification of youth athletes because there is evidence of an association between low scores of cardiorespiratory fitness, muscle strength as well as overall fitness and cardiovascular risk (Artero et al. 2011, Llorente-Cantarero et al. 2012a, Ortega et al. 2008). Thus, children with values below the 20<sup>th</sup> percentile should be targeted and introduced to fitness promoting programs. These initial low performers can be followed longitudinally to see if their motor performance improves over time and if the respective fitness promoting program is successful.

#### 6.1.6 Conclusion

This longitudinal study produced age- and sex-specific physical fitness percentiles for six different test items in healthy children aged 9-12. In girls as compared to boys, physical fitness development was slightly faster for upper-extremity muscular power and agility but substantially faster for flexibility. Furthermore, accelerated (curvilinear) improvements were observed for upper-extremity muscular power (boys: 10-11 years; girls: 9-11 years), agility (boys: 9-10 years; girls: 9-11 years), and endurance (boys: 9-10 years; girls: 9-10 years) indicating a timed and capacity-specific physical fitness development during childhood. As a consequence, sex-specific growth and maturational processes already have an impact on physical fitness development in 9- to 12-year-olds. Most important, the obtained percentile values can be used as approximate benchmarks to identify children with specific fitness characteristics that can be introduced to educational settings (e.g., age- and sex-specific grading of motor performances) as well as to programs for long-term athlete development (i.e., high achievers) and/or to promote health-related physical fitness in low achievers.

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## 6.2 Study 2 – Effect of living area & sports club participation on PF

*Publication title:*

### **Effect of living area and sports club participation on physical fitness in children: A 4 year longitudinal study**

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#### *Reference*

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### 6.2.1 Abstract

Cross-sectional studies detected associations between physical fitness, living area, and sports participation in children. Yet, their scientific value is limited because the identification of cause-and-effect relationships is not possible. In a longitudinal approach, we examined the effect of living area and sports club participation on physical fitness development in primary school children from class three to six. One-hundred and seventy-two children (age: 9-12 years; sex: 69 girls, 103 boys) were tested for their physical fitness (i.e., endurance [9-min run], speed [50-m sprint], lower- [triple hop] and upper-extremity muscle strength [1-kg ball push], flexibility [stand-and-reach], and coordination [star coordination run]). Living area (i.e., urban or rural) and sports club participation were assessed using parent questionnaire. Over the 4 year study period, urban compared to rural children showed significantly better performance development for upper- ( $p = 0.009$ ,  $ES = 0.16$ ) and lower-extremity strength ( $p < 0.001$ ,  $ES = 0.22$ ). Further, significantly better performance development were found for endurance ( $p = 0.08$ ,  $ES = 0.19$ ) and lower-extremity strength ( $p = 0.024$ ,  $ES = 0.23$ ) for children continuously participating in sports clubs compared to their non-participating peers. Our findings suggest that sport club programs with appealing arrangements could be a good means to promote physical fitness in children living in rural areas.

### 6.2.2 Introduction

Physical fitness is an important health determinant that is related to several physiological functions. Recent studies regarding the health burden of chronic diseases revealed significant inverse associations between physical fitness and cardiovascular risk factors (e.g., blood pressure, insulin resistance, cholesterol/lipids, overweight/adiposity) in children and adolescents (Artero et al. 2011, Llorente-Cantarero et al. 2012, Llorente-Cantarero et al. 2012). Further, there is evidence that physical fitness and its health-related outcomes track from childhood over adolescence into adulthood (Bugge et al. 2013, Freitas et al. 2012). In fact, findings from longitudinal studies indicate that higher levels of physical fitness during childhood and adolescence are associated with a healthier cardiovascular profile in adulthood (for a review see Ruiz et al. 2009).

Several non-modifiable (i.e., genetics) (Tucker & Collins, 2012) and modifiable factors influence physical fitness. Modifiable factors can be categorized in behavioral (e.g., physical activity, media use) and environmental (e.g., socioeconomic status, living area) subcategories and are thus of particular interest from a health-promoting perspective (Jimenez-Pavon et al. 2010, Ortega et al. 2008, Zahner et al. 2009). More specifically, the subcategory living area appears to play an important role in moderating physical fitness. Most of the literature on the association between living area and physical fitness observed better performances for children living in rural compared to urban areas (Adamo et al. 2011, Dollman & Norton 2002, Karkera et al. 2013). For example, Dollmann & Norton (2002) showed significantly better results for a measure of endurance (1-mile run) in rural compared to urban children aged 10-11 years. Further, Karkera et al. (2013) reported significantly better performances for rural than for urban school children (9-13 years) in tests for endurance (20-m shuttle run) and flexibility (sit-and-reach). Lastly, Chillon et al. (2011) found mixed results in youth (7-13 years) with rural students better in measures of endurance (20-m shuttle run), muscle endurance (bent-arm hang), and strength (HGS-test) but urban students better in measures of speed (5 x 10-m shuttle run), flexibility (sit-and-reach), and muscle endurance (sit-ups). Even though the reported studies provide further insight in the association between living area and physical fitness, their added scientific value is limited because findings from cross-sectional studies do not allow the identification of cause-and-effect relationships.

Besides the subcategory living area, sports participation represents another factor that is related to physical fitness (Ara et al. 2004, Drenowatz et al. 2013, Zahner et al. 2009). For example, Ara et al. (2004) reported significantly better scores for lower-extremity muscle strength (squat jump), endurance (20-m shuttle run), and speed (sprint tests over 30 and 300 m) in boys (8-11 years) participating in a sport club as compared to their non-participating classmates. In support of this finding, Drenowatz et al. (2013) observed significantly better results in sports club participating children ( $7 \pm 1$  years) for endurance (6-min run), upper-extremity muscle strength (medicine ball throw), coordination (throw-and-turn), and balance (one-leg balancing) compared to their non-participating peers. However, the above mentioned studies are limited because they applied a cross-sectional and not a longitudinal design. Thus, longitudinal data is needed to provide

conclusive evidence whether sports participation and/or living area really represent determinants of physical fitness development in children.

Therefore, this study used a longitudinal approach and we aimed at investigating differences in physical fitness levels over time (i.e., class three to six) between children living in urban as compared to rural areas and between sports club participating children and their non-participating peers. Based on the literature (Adamo et al. 2011, Dollman & Norton 2002, Karkera et al. 2013), it is hypothesized that physical fitness level and its development is better in children living in rural compared to urban areas. In addition, it is expected that children continuously participating in sports clubs show better physical fitness levels as well as larger fitness development rates than their non-participating peers.

### 6.2.3 Methods

#### *Sample and study design*

A longitudinal study was conducted to test changes in physical fitness in the same children over time (i.e., from class three to class six). This time frame was chosen because the involved sports clubs search for talented children. The participating children attended public primary schools ( $N = 24$ ) that were randomly selected from urban (i.e., cities  $> 10,000$  inhabitants) and rural (i.e., cities/villages  $\leq 10,000$  inhabitants) areas of the federal state Brandenburg (Germany). This classification was made according to the federal statistics report (Ministerium für Landwirtschaft 2009). Over the four year study, the annual testing period lasted four weeks (i.e., from March to April) each year. The study was approved by the Ministry of Education, Youth and Sport of the federal state Brandenburg committee and the parents or legal representatives of each child provided written informed consent. The study was conducted according to the declaration of Helsinki. Of the initially recruited 341 children, informed consent and valid data were obtained from 172 children (69 girls, 103 boys) over the four-year period. This data set was used for further analyses.

#### *Anthropometry*

Body height was measured without shoes to the nearest 0.5 cm with a wall-mounted stadiometer (Seca, Basel, Switzerland). Body mass was determined in light clothing and without shoes to the nearest 100 g with an electronic scale (Bodymaster vision BM-210, Rowenta, France). Body mass index (BMI) was calculated using body mass divided by height squared ( $\text{kg}/\text{m}^2$ ).

#### *Physical fitness testing*

Physical fitness was determined with 6 different tests from motor fitness test batteries of Bös (Bös 2001, 2009) and Stark (Stark 2000) in the same children starting in class 3 and repeated in class 4, 5, and 6. The tests included the following items: 50-m sprint, 1-kg ball push, triple hop, stand-and-reach, star coordination run, and 9-min run. Test-retest reliability of these tests ranged from  $r = 0.70$  to  $0.94$  (Bös 2001, 2009, Fetz & Kornexl 1978). A description of all test items is provided in Table 8. All tests were performed in the respective school gyms following standardized test protocols (e.g., test instructions).

**Table 8:** Description of all physical fitness test items (Bös 2001, 2009, Stark 2001) and the respective motor ability (in parentheses).

Fitness test item	Fitness test description	Score
star coordination run (agility)	- minimal time needed to run from the center to the edge and back of a star with 4 spikes	s
9-min run (endurance)	- maximal distance achieved during 9 minutes	m
stand-and-reach (flexibility)	- maximal reach while standing with extended knees	cm
50-m sprint (speed)	- minimal time needed on a 50-m run	s
triple hop (lower-extremity strength)	- maximal horizontal jump distance	m
1-kg ball push (upper-extremity strength)	- maximal pushing distance	m

### *Questionnaire*

Parents filled out a questionnaire that was sent home. Questions contained information regarding the subcategories living area (rural or urban) and sports club participation (Yes or No option). Only children that did not change their residential status (n=172) over the four-year study period were included for further analyses with 66 of them that continuously participated in a sports club or not.

### *Statistical analyses*

Data are presented as group mean values and standard deviations. Physical fitness parameters were analysed in separate sex-adjusted analyses of variance (ANOVA) with repeated measures on class. Post-hoc tests with the Bonferroni-adjusted  $\alpha$  were conducted to identify the comparisons that were statistically significant. The classification of effect size (ES) was determined by calculating partial  $\eta^2_p$ . According to Cohen (1988) ES can be classified as small ( $0.00 \leq ES \leq 0.24$ ), medium ( $0.25 \leq ES \leq 0.39$ ), and large ( $ES \geq 0.40$ ). In addition, odds ratios (OR) and 95% confidence interval (CI) were calculated using the chi-square test to determine associations between living area and sports club participation. The significance level was set at  $p < 0.05$ . All analyses were performed using Statistical Package for the Social Sciences (SPSS) version 22.0.

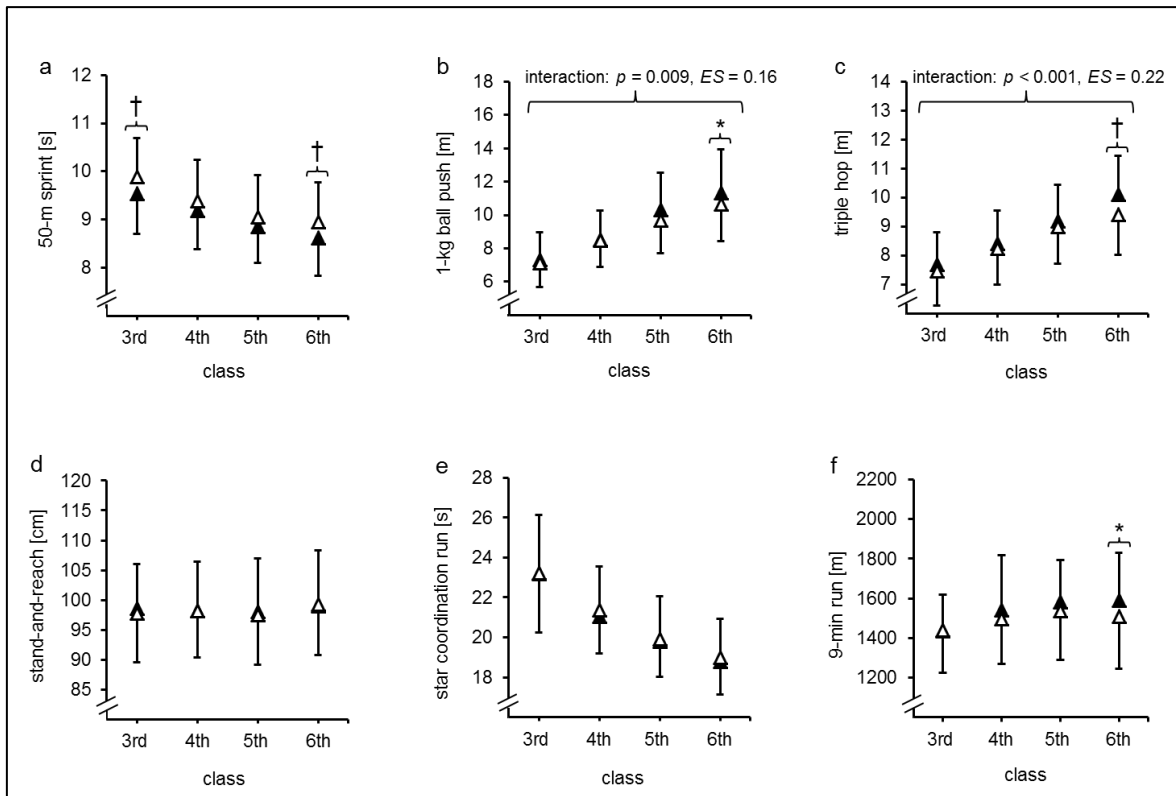


#### 6.2.4 Results

Anthropometric and physical fitness test data of the study sample sorted by class and sex are presented in Table 9. Boys were significantly taller than girls in the third and fourth class (both  $p < 0.05$ ). Eighty-nine children lived in an urban (boys: 51%, girls: 52%) and 83 children in a rural (boys: 49% girls: 48%) area. Over the four-year experimental period, 49 children (boys: 79%, girls: 67%) continuously participated in a sports club at least once a week and the 17 children (boys: 21% girls: 33%) had never participated in a sports club ( $p < 0.05$ ). Thirty-two urban (36%) and 17 rural (20%) children continuously participated in a sports club. The correlative analysis regarding living area and sports club participation revealed that living in rural areas is more likely associated with not participating in a sports club ( $n = 66$ , OR = 2.7, 95% CI = 0.87-8.33) compared to living in urban areas. The number of practiced sports significantly differed ( $p < 0.001$ ) between urban (i.e., 27 different sports) and rural (i.e., 13 different sports) children.

##### *Effect of living area on physical fitness development*

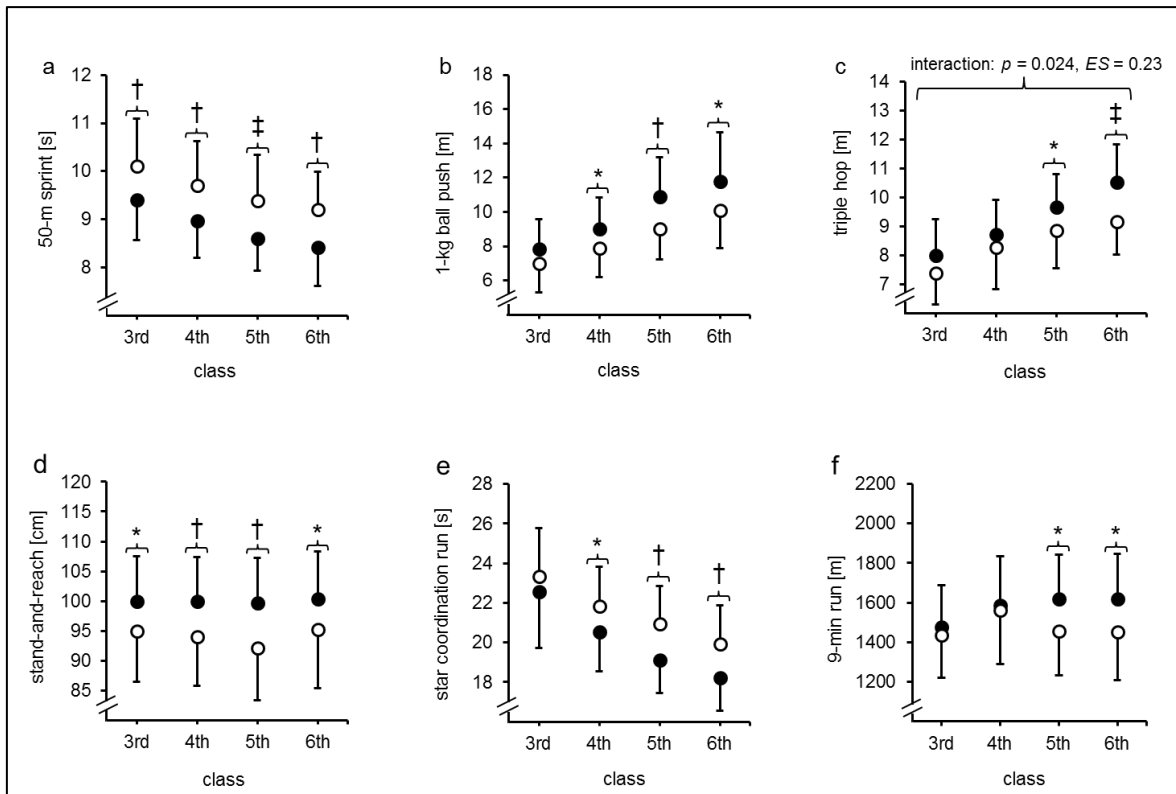
Statistically significant interaction effects of class x living area were detected for the 1-kg ball push ( $F_{[3, 510]} = 4.2$ ,  $p = 0.009$ ,  $\eta^2_p = 0.024$ , ES = 0.16) and for the triple hop test ( $F_{[3, 510]} = 8.1$ ,  $p < 0.001$ ,  $\eta^2_p = 0.046$ , ES = 0.22) (Table 10). Further, significant main effects of class were found for all physical fitness tests (all  $p \leq 0.020$ , ES = 0.14-0.62). Additionally, the main effect of living area was significant for the 50-m sprint test ( $F_{[1, 170]} = 5.8$ ,  $p = 0.017$ ,  $\eta^2_p = 0.033$ , ES = 0.18). In sixth graders, post-hoc analyses indicated significantly better performances in 4 out of 6 physical fitness tests (i.e., 50-m sprint, 1-kg ball push, triple hop, 9-min run) in favor of children living in urban compared to rural areas (Figure 11 a-f).



**Figure 11:** Development of physical fitness in primary school children according to grade and living area: (a) 50-m sprint, (b) 1-kg ball push, (c) triple hop, (d) stand-and-reach, (e) star coordination run, and (f) 9-min run. Notes. \*  $p < 0.05$ ; †  $p < 0.01$ ; Filled triangles indicate urban and unfilled triangles indicate rural children.

#### *Effect of sports club participation on physical fitness development*

Due to the fact that living in rural areas is more likely associated with not participating in a sports club, the factor living area was included as a covariate in our statistical model. As a result, statistically significant interaction effects of class x sports club participation were detected for the triple hop test ( $F_{[3, 192]} = 3.2$ ,  $p = 0.024$ ,  $\eta^2_p = 0.049$ ,  $ES = 0.23$ ) and for the 9-min run test ( $F_{[3, 192]} = 2.3$ ,  $p = 0.083$ ,  $\eta^2_p = 0.035$ ,  $ES = 0.19$ ) (Table 11). Further, significant main effects of class were observed in all (all  $p \leq 0.023$ ,  $ES = 0.24$ - $0.30$ ) but two physical fitness test (i.e., stand-and-reach, 9-min run). Additionally, the main effect of sports club participation turned out to be significant (all  $p \leq 0.030$ ,  $ES = 0.28$ - $0.44$ ) in all but one physical fitness tests (i.e., 9-min run). Post-hoc analyses indicated significantly better performances in all physical fitness tests for children participating in sport clubs compared to those who did not. This is particularly prevalent for fifth- and sixth-graders (Figure 12 a-f).



**Figure 12:** Development of physical fitness in primary school children according to class and sports club participation: (a) 50-m sprint, (b) 1-kg ball push, (c) triple hop, (d) stand-and-reach, (e) star coordination run, and (f) 9-min run. Notes. \*  $p < 0.05$ ; †  $p < 0.01$ ; ‡  $p < 0.001$ ; Filled circles indicate children with and unfilled circles indicate children without continuous sports club participation.

**Table 9:** Description of the study sample (103 boys, 69 girls) by class and sex.

Characteristic	3 <sup>rd</sup> class		4 <sup>th</sup> class		5 <sup>th</sup> class		6 <sup>th</sup> class	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Age (yr)	9.4 (0.4)*	9.2 (0.4)	10.3 (0.4)*	10.2 (0.4)	11.4 (0.5)*	11.2 (0.3)	12.4 (0.4)*	12.2 (0.4)
Height (cm)	139.8 (5.9)*	136.9 (6.4)	143.6 (6.2)*	141.6 (6.9)	150.0 (6.8)	148.8 (7.7)	156.2 (7.7)	154.9 (7.6)
Mass (kg)	32.0 (5.0)	31.6 (5.9)	35.9 (6.0)	35.9 (7.8)	40.6 (7.4)	40.7 (10.1)	45.7 (8.6)	45.8 (11.2)
BMI (kg/m <sup>2</sup> )	16.4 (2.1)	16.8 (2.4)	17.4 (2.4)	17.8 (3.0)	18.0 (2.5)	18.2 (3.4)	18.6 (2.6)	19.0 (3.7)
<i>Fitness test</i>								
50-m sprint (s)	9.6 (0.8)	9.9 (0.8)	9.2 (0.8)*	9.5 (0.9)	8.9 (0.8)	9.1 (0.8)	8.7 (0.8)	8.9 (0.8)
1-kg ball push (m)	7.82 (1.4)*	6.33 (1.4)	9.09 (1.6)*	7.61 (1.3)	10.76 (2.0)*	8.93 (1.9)	11.78 (2.3)*	9.8 (2.2)
triple hop (m)	7.76 (1.2)*	7.30 (1.1)	8.51 (1.2)*	8.04 (1.2)	9.29 (1.3)*	8.81 (1.2)	9.97 (1.4)*	9.5 (1.4)
SaR (cm)	96.5 (7.8)*	100.7 (7.2)	96.6 (8.1)*	100.6 (7.2)	95.3 (8.5)*	101.6 (7.4)	96.0 (8.3)*	103.9 (7.8)
star run (s)	22.9 (3.3)	23.6 (2.3)	20.8 (2.0)*	21.8 (1.9)	19.5 (2.0)*	20.4 (1.8)	18.6 (1.8)*	19.3 (1.7)
9-min run (m)	1499.5 (193.1)*	1343.4 (168.3)	1587.9 (255.2)*	1417.1 (213.9)	1629.2 (235.9)*	1455.8 (177.9)	1610.4 (254.7)*	1463.3 (229.3)

*Notes.* Values are means ( $\pm$  SD). \* indicates that boys are significantly different from girls ( $p < 0.05$ ); BMI = Body Mass Index; SaR = stand-and-reach test; star run = star coordination run

**Table 10:** Results of the ANOVA (adjusted for sex) with repeated measures on class by living area.

Main/interaction effect	<i>F</i> -value	<i>df</i>	<i>p</i> -value	partial $\eta^2$	<i>ES</i>
50-m sprint class	17.8	3	0.000	0.095	0.32
50-m sprint area	5.8	1	0.017	0.033	0.18
50-m sprint class x area	1.9	3	0.131	0.011	0.11
1-kg ball push class	65.6	3	0.000	0.280	0.62
1-kg ball push area	2.8	1	0.099	0.016	0.13
1-kg ball push class x area	4.2	3	0.009	0.024	0.16
triple hop class	52.5	3	0.000	0.237	0.56
triple hop area	3.4	1	0.066	0.020	0.14
triple hop class x area	8.1	3	0.000	0.046	0.22
SaR class	6.8	3	0.000	0.039	0.20
SaR area	0.0	1	0.855	0.000	0.00
SaR class x area	0.9	3	0.429	0.005	0.07
star run class	35.2	3	0.000	0.172	0.46
star run area	0.4	1	0.534	0.002	0.04
star run class x area	0.5	3	0.654	0.003	0.05
9-min run class	3.4	3	0.020	0.019	0.14
9-min run area	2.4	1	0.127	0.014	0.12
9-min run class x area	2.4	3	0.074	0.014	0.12

*Notes.* SaR = stand-and-reach test; star run = star coordination run; area = living area; *df* = degrees of freedom; *ES* = effect size.

**Table 11:** Results of the ANOVA (adjusted for sex and living area) with repeated measures on class by sports club participation.

Main/interaction effect	<i>F</i> -value	<i>df</i>	<i>p</i> -value	partial $\eta^2$	<i>ES</i>
50-m sprint class	3.5	3	0.023	0.053	0.24
50-m sprint participation	10.8	1	0.002	0.148	0.42
50-m sprint class x participation	0.1	3	0.915	0.002	0.04
1-kg ball push class	4.3	3	0.011	0.064	0.26
1-kg ball push participation	4.9	1	0.030	0.074	0.28
1-kg ball push class x participation	1.1	3	0.357	0.017	0.13
triple hop class	5.5	3	0.001	0.081	0.30
triple hop participation	5.2	1	0.026	0.078	0.29
triple hop class x participation	3.2	3	0.024	0.049	0.23
SaR class	1.6	3	0.199	0.025	0.16
SaR participation	11.9	1	0.001	0.162	0.44
SaR class x participation	1.7	3	0.167	0.027	0.17
star run class	3.8	3	0.021	0.057	0.25
star run participation	6.8	1	0.012	0.098	0.33
star run class x participation	1.2	3	0.322	0.018	0.14
9-min run class	0.2	3	0.924	0.003	0.06
9-min run participation	1.9	1	0.173	0.030	0.18
9-min run class x participation	2.3	3	0.083	0.035	0.19

*Notes.* SaR = stand-and-reach test; star run = star coordination run; area = living area; *df* = degrees of freedom; *ES* = effect size.

### 6.2.5 Discussion

To the authors' knowledge, this is the first study that investigated in a longitudinal approach the effects of living area and sports club participation on physical fitness development in healthy children from class three to six. The main findings can be summarized as follows: (1) over the 4 year study period, children living in urban as compared to rural areas showed a significantly better performance development for upper- (1-kg ball push) and lower-extremity muscle strength (triple hop test) and (2) children participating in sport clubs showed a significantly better performance development over the 4 year study period for measures of endurance (9-min run) and lower-extremity muscle strength (triple hop test) as compared to their non-participating peers.

#### *Living area and the development of physical fitness*

In addition to the already existing cross-sectional studies, the present investigation provided data originating from a longitudinal study approach over a four-year experimental period. As a result, it was found that living area has a positive effect on the development of physical fitness in children in terms of significantly better performance increments for children living in urban compared to rural areas. This was detected in significant findings for upper- (1-kg ball push) and lower-extremity muscle strength (triple hop test).

It is of interest to note that our results regarding better physical fitness in urban as compared to rural children are in contrast to most of the studies reported in the literature (Adamo et al. 2011, Chillon et al. 2011, Dollman & Norton 2002, Karkera et al. 2013, Ozdirenc et al. 2005, Wang et al. 2013). This discrepancy can most likely be explained by looking at the specific fitness items that were applied in the different studies. In fact, better values for upper- (1-kg ball push) and lower-extremity muscle strength (triple hop) were found in the present study, whereas better endurance performances (20-m shuttle run; 1-mile run) were detected in other studies (Adamo et al. 2011, Chillon et al. 2011, Dollman & Norton 2002, Karkera et al. 2013). Another reason that might account for the differences in findings, results from the methodological approaches that were used to distinguish between urban and rural living areas (e.g., number of inhabitants). In contrast to our study (urban: > 10,000 inhabitants), Tambalis et al. (2011) used a cut-off value of > 5,000 inhabitants to differ between urban and rural living areas. As a consequence, areas that we defined as rural (i.e.,  $\leq 10,000$  inhabitants) were classified as urban in the aforementioned study (Tambalis et al. 2011). Additionally, in the present study the definition of rural and urban living areas was based on a federal statistics report. In contrast, Pena Reyes et al. (2003) and Tsimeas et al. (2005) did not report the respective reference for their classification procedure. Furthermore, the developing status of the country (i.e., industrialized country vs. emerging economy) in which the study was carried out could also have an impact. The present study was conducted in an industrialized country (i.e., Germany), whereas the study of Karkera et al. (2013) investigated children from India, which is an emerging economy. In fact, it has been reported that children's physical fitness and development differs between low- and high-income economies (Adamo et al. 2011, Bielicki 1986, Tomkinson 2007).

*Sports club participation and the development of physical fitness*

The results of this study illustrated that, irrespective of living area, children participating in sports clubs showed better physical fitness development than their non-participating peers. The findings of our longitudinal approach are in accordance with that of cross-sectional studies concerning a positive association of sports club participation and physical fitness (Ara et al. 2004, Drenowatz et al. 2013, Zahner et al. 2009). For example, Ara et al. (2004) showed significantly better results in endurance (20-m shuttle run), lower-extremity muscle strength (squat jump), and speed (sprint tests over 30 and 300 m) in boys (8-11 years) participating in extracurricular sports activities as compared to their non-participating peers. In the present study, the effects of sports club participation on physical fitness development were found as a trend regarding endurance (9-min run) and as a significant finding for lower-extremity muscle strength (i.e., triple hop). Our finding regarding better physical fitness development in sports club participating children may be attributed to the formal and structured organizational frame in which physical activity takes place. In fact, Silva et al. (2013) reported for boys and girls aged 11-18 years that engagement in organized sports outside school was associated with a higher level of moderate to vigorous physical activity (MVPA). Participation in organized extracurricular sports seems to be of great public health importance considering the fact that the recommended amount of at least 60 minutes of moderate to vigorous physical activity a day (WHO, 2010) is not sufficiently achieved through physical education classes at school. More specifically, the average amount of time spent in physical education classes during primary school in Germany amounts to 135 minutes per week (i.e., 3 x 45 min /week). This is not enough to fulfill the above-mentioned physical activity guidelines provided by the World Health Organization (2010). Additionally, a study conducted with 6- to 12-year-old boys revealed that physical education lessons covered only 11% of the total daily MVPA (Wickel & Eisenmann, 2007). In the same study, it was shown that organized youth sports covered another 23% of the total daily MVPA. Therefore, it is necessary to search for strategies inside and outside school to increase children's physical activity and fitness levels. Organized extracurricular sports such as participation in a sports club appears to be a promising means to increase physical activity (Silva et al. 2013) and to enhance health-related behavior in youth (Pate et al. 2000). Further, the arrangement of social commitments is particularly important during adolescence to provide additional stimuli to be physically active (Petitpas & Champagne 2000). In this context, sports clubs may represent a natural environment adolescents like to commit themselves to because they can practice sports with their peers. For example, Carreres-Ponsoda et al. (2012) observed in 12-19 year old boys and girls that those participating in out-of-school sport programs have significantly higher levels of self-efficacy, pro-social behavior as well as personal and social responsibility compared to their peers who do not participate in such programs. In summary, due to the link between physical fitness and several health-related outcomes in youth (Artero et al. 2011, Chen et al. 2006) as well as the tracking of physical fitness from youth to adulthood (Ruiz et al. 2009, Twisk et al. 2000), more emphasis should be laid on establishing sports clubs as an easy and attractive means to promote health-enhancing daily physical activity. However, it should be noted further factors (e.g., hours watching TV or

playing computer games) that were not investigated in the present study could also have an impact and should be target too.

#### 6.2.6 Conclusion

Findings from the present study indicate that the development of physical fitness is positively affected by living area and sports club participation. More specifically, children living in urban areas and children participating in sports clubs were fitter and fitness progressed faster than in their counterparts in terms of endurance (9-min run), upper- (1-kg ball push) and lower-extremity muscle strength (triple hop test). From a health perspective, these are important findings because deficits in muscle strength represent intrinsic injury and fall-related factors in youth (Crawley-Coha 2001, Knapik et al. 1991). Additionally, a high level of cardiorespiratory fitness is related to a lower risk in many health-related outcomes (e.g., waist circumference, blood pressure, insulin level) in children (Ekelund et al. 2007). As a consequence sports club programs offering appealing arrangements could be a good means to increase physical fitness in children living in rural areas.



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### 6.3 Study 3 – Socioeconomic differences in PF

*Publication title:*

#### **Socioeconomic differences in physical fitness in primary school-aged children**

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### 6.3.1 Abstract

There is only limited information available on the impact of socioeconomic status (SES) on physical fitness in children. In a cross-sectional approach, we examined socioeconomic differences in physical fitness in healthy children. The study involved 12,460 children (age:  $8.6 \pm 0.5$  years; sex: 6,289 boys and 6,171 girls) that were tested for their physical fitness (i.e., 6-min run, 20-m sprint, standing long jump, 1-kg medicine ball push, stand-and-reach, star agility run). Methods: SES was determined including the following factors: proportion of the population with higher education, monthly average household income, recipients/job seekers receiving basic security benefits. Results: Irrespective of sex, our analyses revealed a significantly higher proportion of students in the high compared to the middle and/or low SES-groups with high fitness levels (i.e., 6-min run test, standing long jump test). Further, analyses of covariance revealed significantly better performances for 6-min run (boys:  $p=.001$ ; girls:  $p=.016$ ), standing long jump (boys:  $p<.001$ ; girls:  $p<.001$ ), and star agility run (boys:  $p=.004$ ; girls:  $p=.045$ ) in favor of children with high SES background. Conclusion: Our results revealed significant socioeconomic differences in physical fitness in children. Irrespective of sex, larger numbers of children with above average fitness levels live in communities with high SES. Further, children in the high SES-group outperformed those in the middle and/or low SES-groups. Therefore, special emphasis should be placed on intervention strategies that promote physical fitness in students living in low and middle SES communities.

### 6.3.2 Introduction

Socioeconomic status (SES) is influenced by a number of personal (education, occupation, income, ethnic group etc.) and societal factors (e.g., family, neighborhood) (Matthews & Gallo 2011). In youth, most studies investigating the role of SES on physical activity (PA) or health-related outcomes indicated a relationship between low SES and the prevalence of overweight/ obesity (Bohr et al. 2013, Haas et al. 2003, Janssen et al. 2006), and cardiovascular risk factors (e.g., elevated levels of skinfold thickness, blood pressure, and high-density lipoprotein) (Van Lenthe et al. 2001). However, only limited information is available regarding potential associations between SES and physical fitness in youth in general and in children in particular. In addition, the few published studies are methodologically flawed due to relatively small sample sizes (Freitas et al. 2007, Kristensen et al. 2006, Van Lenthe et al. 2001), the inclusion of only one physical fitness measure (Kristensen et al. 2006, Mutunga et al. 2006, Van Lenthe et al. 2001), and/or inconsistent findings (Bohr et al. 2013, Freitas et al. 2007). For example, Kristensen et al. (2006) compared performance in a progressive maximal cycle ergometer test in 503 third graders (8-10 years) of different SES background. SES was classified using the occupational status of the mother. Thus, children of blue-collar workers were categorized as low SES and children of white-collar workers as high SES. Results indicated significantly better ergometer performance in children of high compared to low SES. Contrary to this finding, Van Lenthe et al. (2001) did not observe any significant differences in endurance (20-m shuttle run test) in children (N = 509) aged 12 of different SES backgrounds. In this context, SES was based on the occupational status (high SES = non-manual occupations, low SES = manual occupations) of the person with the main family income. Lastly, Freitas et al. (2007) assessed physical fitness using the Eurofit test battery in 8- to 18-year-olds (N = 507). The applied SES index included five factors (i.e., parental occupation, education, income, housing, and residential area). The authors reported inconsistent results for students of high SES. In fact, poorer performances were found for measures of endurance (12-min run), muscular strength endurance (bent-arm hang), and speed (plate tapping) in students of the high SES group as compared to those in the low and/or middle SES-groups. Of note, better balance performance (flamingo stance) was reported for students in the high SES-group compared to students in the low and/or middle SES-groups. This study further revealed that SES primarily influenced physical fitness in males but to a lesser extent in females.

Additional evidence for sex-specific relationships between SES and physical fitness comes from Bohr et al. (2013). These authors tested 954 adolescents (classes 6 to 8) that were classified either in low or high SES depending on the allowance to participate in a federal free lunch program for their physical fitness using the FITNESSGRAM battery. Contrary to the findings of Freitas et al. (2007), Bohr et al. observed significantly better performances in measures of endurance (20-m shuttle run test) and muscle strength endurance (curl-ups, push-ups) in favor of the girls but not the boys in high SES-group. In summary, it is unresolved whether SES represents a determinant of physical fitness in general and whether sex has a moderating effect. In-depth knowledge on this issue is useful

to develop and design specifically tailored intervention programs that are appropriate to mitigate the influence of low SES on physical fitness. Thus, the purpose of this study was to examine associations between SES and physical fitness in a large sample of primary school-aged healthy boys and girls. We hypothesized better physical fitness levels in students living in high SES communities compared to those living in middle and/or low SES communities. Further, we expect that SES produces sex-specific differences in physical fitness.

### 6.3.3 Methods

#### *Sample and study design*

A cross-sectional study was conducted to test differences in physical fitness of third graders living in communities of low, middle, or high SES. The participating children were recruited from 368 public schools in the federal state Brandenburg (Germany). Characteristics of the study participants are summarized in Table 12. The testing period lasted four weeks (i.e., from beginning to end of September). The study was approved by the Ministry of Education, Youth and Sport of the federal state Brandenburg. The study was conducted according to the latest revision of the declaration of Helsinki. Parents or legal representatives of each child provided written informed consent. Of the initially recruited 14,041 children (7,080 boys and 6,961 girls), valid data were obtained from 12,460 children (6,289 boys and 6,171 girls).

**Table 12:** Characteristics of the study participants by physical fitness level and sex.

	low fit			high fit		
	<i>N</i> (f)	male	female	<i>N</i> (f)	male	female
20-m sprint (s)	3396 (1750)	5.0 (0.4)	5.1 (0.4)	2677 (1480)	3.8 (0.2)	4.0 (0.2)
ball push (m)	2908 (1264)	3.1 (0.3)	2.6 (0.3)	3464 (1660)	4.9 (0.5)	4.3 (0.4)
SLJ (cm)	2844 (1320)	104 (10)	97 (9)	3237 (1660)	155 (9)	145 (9)
SaR (cm)	2876 (1379)	89 (5)	92 (5)	3495 (1652)	106 (4)	109 (3)
star run (s)	3134 (1548)	30.6 (3.7)	31.3 (3.4)	3024 (1502)	20.5 (1.4)	21.4 (1.5)
6-min run (min.)	3057 (1519)	836 (106)	797 (82)	3264 (1571)	1242 (102)	1139 (78)

*Notes.* Data are means and standard deviations. f = female; ball push = 1-kg medicine ball push test; SLJ = standing long jump test; SaR = stand-and-reach test; star run = star agility run test.

### *Organized sports participation*

Prior to physical fitness testing, a standardized protocol was used to assess whether children participated in organized sports. Organized sports participation was defined as actively participating in sports clubs and/or in extra-curricular physical education classes at least once a week (Yes or No option for both forms of sports participation). Children who actively participated in at least one out of the two given options were classified as 'organized sports participation'.

### *Physical fitness testing and categorization*

Six tests were taken from different motor fitness test batteries to assess physical fitness (Bös 2001, Stark 2000). The following test items were included in this study: 20-m sprint test (speed), 1-kg medicine ball push test (upper-extremity muscle strength), standing long jump test (lower-extremity muscle strength), stand-and-reach test (flexibility), star agility run test (agility), and 6-min run test (endurance). All tests were performed in the respective school gyms during official physical education lessons using standardized test protocols. Before testing, all students followed a 10 minutes warm-up program consisting of light running including coordinative exercises (e.g., side steps, backwards run, skipping), submaximal plyometric exercises, and short distance sprints.

For each physical fitness test, age- and sex-specific quartiles were calculated to classify children as low fit (i.e., lower quartile:  $\leq$  25th percentile) or high fit (i.e., upper quartile:  $>$  75th percentile) (Anderssen et al. 2007). Notably, low scores indicate better performances in two out of six test items (i.e., 20-m sprint test, star agility run test). For these 2 tests, lower quartiles ( $\leq$  25th percentile) were defined as high fitness level and upper quartiles ( $>$  75th percentile) as low fitness level. In general, a student was classified as low fit when his/her performance was  $\leq$  25% of all participating children. In contrast, a student was classified as high fit when his/her performance was  $>$  75% of all children.

#### 20-m sprint test

Speed performance was assessed in a stationary starting position. Participants were instructed to stand with one foot right behind the starting line in frontal erect posture. On the command 'ready-set-go', students started their first trial and accelerated at maximum effort. Time was taken with a stop watch to the nearest 1/10 s. The best out of two trials (i.e., minimal sprint time) with a five minute rest between trials was used for further data analysis. The 20-m sprint test is a reliable test ( $r = 0.90$ ) for the assessment of speed in 7- to 11-years-olds (Bös 2009).

#### Ball push test

Muscular strength of the upper extremities was assessed using the 1-kg medicine ball push test (Bös et al. 2001). Participants were instructed to stand with both feet right behind a starting line in frontal erect position and to bimanually push the ball from the chest forward as hard as they can. Distance was taken with a measuring tape to the nearest centimeter. The best out of two trials (i.e., maximal distance) with a one minute rest between trials was used for further data analysis. The 1-kg medicine ball push test is a reliable test (ICC =



0.82) for the assessment of upper-body muscular strength in 8- to 10-years olds (Schulz, 2013).

#### Standing long jump test

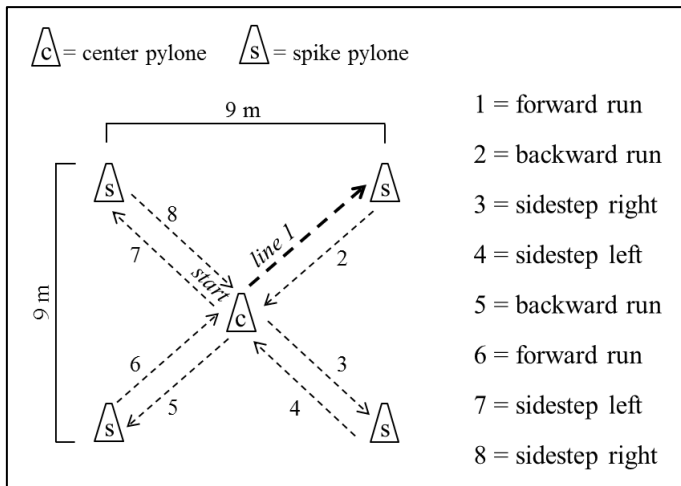
Lower-extremity muscle strength was tested using the standing long jump test. Participants were instructed to stand with both feet right behind a starting line and to jump as far as possible. Subjects were allowed to use arm swing during the test. Two trials were performed with a one minute rest between trials. The best trial in terms of maximal distance from the starting line to the landing point at heel contact was used for statistical analysis. Measurements were taken to the nearest centimeter using a tape measure. The standing long jump test is a reliable test ( $r = 0.89$ ) for the assessment of lower-extremity muscular strength in 7- to 11-years-olds (Bös 2009).

#### Stand-and-reach test

Flexibility was tested using the stand-and-reach test. Subjects were instructed to begin the test in a standing position on an elevated platform with feet together. They were asked to bend over using their maximal range of motion during expiration. During the test, knees, arms, and fingers were fully extended for at least two seconds. A tape measure was attached to the platform with 100 cm corresponding to the upper level of the platform. Values above 100 cm indicate that the person was able to reach beyond the toes (i.e., good flexibility). Values below 100 cm indicate that the person was not able to reach the toes (i.e., limited flexibility). The best out of two trials (i.e., maximal reach distance) with a one minute rest between trials was used for further data analysis. The stand-and-reach test is a reliable test ( $r = 0.94$ ) for the assessment of flexibility in 7- to 11-years-olds (Bös 2009).

#### Star agility run test

Agility was tested using the star agility run test (Stark 2000). Participants were instructed to run in different running techniques (e.g., forward, backward, side steps) from the center to the edge and back of a 9 x 9-m star-shaped field with four spikes (Figure 12). The spikes and the center of the field were each marked with pylons (height: 30 cm). Starting at the center of the field, the participants had to run forward to spike 1 (line 1) and backward to the center (line 2). From the center, they turned to the right side and side-stepped to spike 2 (line 3), turned to the left side and side-stepped back to the center (line 4). Upon reaching the center, students turned backward and ran to spike 3 (line 5) and forward to the center (line 6). Finally, they turned to the left side and side-stepped to spike 4 (line 7), turned to the right side and side-stepped back to the center (line 8). During the test, subjects had to touch the top of the pylons at each respective spike and when passing the center position. Time was taken with a stop watch to the nearest 1/10 of a second. Subjects performed one practice trial and thereafter two test trials with a five minute rest in between. The best trial (i.e., least running time) was used for further data analysis. The star agility run test proved to be reliable with an ICC of 0.68 in 8- to 10-years-olds (Schulz 2013).



**Figure 13:** Schematic description of the star agility run test.

### 6-min run test

The 6-min run test is a test for the assessment of aerobic endurance capacity. On the command 'ready-set-go', participants started their run. Split time was given every minute. The maximal distance achieved in six minutes was used for further data analysis. Excellent reliability has been reported for the 6-min run test with a  $r$ -value of 0.92 in 7- to 11-years-olds (Bös, 2009).

### Socioeconomic status

SES was determined for each of the 419 communities of the federal state Brandenburg, Germany. For this purpose, statistics from the Federal Employment Agency (Germany) and the Geomarketing-community Acxiom<sup>®</sup> (Germany) were used (Acxiom 2011, Federal employment office 2011). Factors for defining SES were (a) percentage of population with a university degree, (b) monthly average household income, and (c) percentage of recipients of basic security benefits for job seekers. In a first step, each of the three factors was rated on a five unit scale, with 5 points indicating best parameter value and 1 point worst parameter value. More specifically, percentage of population with a university degree:  $18.5 \leq \% \leq 43.2 = 5$  points,  $12.4 \leq \% \leq 18.3 = 4$  points, [...],  $0.1 \leq \% \leq 5.7 = 1$  point; monthly average household income:  $3,196 \leq \text{€} \leq 4,491 = 5$  points,  $2,757 \leq \text{€} \leq 3,068 = 4$  points, [...],  $1,871 \leq \text{€} \leq 2,422 = 1$  point; percentage of recipients of basic security benefits for job seekers (per 1,000 inhabitants):  $1.8 \leq \% \leq 7.4 = 5$  points,  $7.5 \leq \% \leq 10.3 = 4$  points, [...],  $18.4 \leq \% \leq 34.4 = 1$  point. Afterwards, items were averaged and mean values were divided in tertiles resulting in three equally sized groups representing communities with high ( $n = 136$ ), middle ( $n = 142$ ), and low ( $n = 141$ ) SES. During the experimental period of this study, 445 public primary schools existed in the federal state of Brandenburg and those were located in 239 communities. The recruited sample of 368 schools (83%) was located in 217 communities. Seventy-three of those 217 communities were classified as low SES, 70 as middle SES, and 74 as high SES. With respect to the included schools, most schools ( $n = 153$ ) were located in communities of middle SES followed by schools in communities of high SES ( $n = 111$ ) and of low SES ( $n = 101$ ).

Differences in numbers of schools per SES-group can be explained by the fact that middle and high SES were mostly present in communities with many inhabitants. As a consequence, students in the present study were not equally distributed over the three SES-groups. In fact, 2,699 children (21.7%; 1,358 boys and 1,341 girls), 5,260 children (42.2%; 2,623 boys and 2,637 girls), and 4,501 children (36.1%; 2,308 boys and 2,193 girls) attended schools in communities of low, middle, and high SES, respectively.

#### *Statistical analyses*

Metric variables (i.e., physical fitness) were expressed as group mean values and standard deviations. Nominal variables (i.e., SES, physical fitness level) were described as relative frequencies. Equal distribution of SES categories (i.e., low, middle, high) by fitness level (i.e., low, high) was compared using chi-square test ( $\chi^2$ ). Analysis of covariance (ANCOVA) was used to investigate differences in physical fitness parameters between SES groups for boys and girls, separately. More specifically, a type III model was used which is relatively robust against imbalanced data distribution across SES groups (Field, 2013). In addition, ANCOVA was adjusted for the following two confounding variables: age and organized sports participation. F-tests with the Bonferroni adjusted  $\alpha$  were conducted for multiple comparisons to identify the comparisons that were statistically significant. The significance level was set at  $p < .05$ . All analyses were performed using Statistical Package for the Social Sciences (SPSS) version 22.0.

#### 6.3.4 Results

##### *Distribution of socioeconomic status by fitness level*

Relative frequencies in SES categories by fitness level are shown in Table 13. These findings illustrate the number of subjects in each SES group who achieved a low or a high physical fitness level. Irrespective of sex, a significantly higher proportion of students with high fitness levels in the standing long jump test ( $p < .001$  for both sexes) and the 6-min run test (male:  $p = .001$ , female:  $p = .037$ ) were found in the high as compared to the middle and low SES-groups. For the ball push test, the proportion of high-fit girls was significantly higher ( $p = .003$ ) in the middle compared to the low and the high SES-groups. For the star agility run test, the percentage of low fit students was significantly lower in the middle (male:  $p = .007$ , female:  $p = .015$ ) than in the high and low SES-groups. No significant differences in distribution of SES by fitness level were found for the 20-m sprint test and the stand-and-reach test.

**Table 13:** Relative frequencies (%) in categories of socioeconomic status (SES) according to physical fitness level (low-fit:  $\leq 25^{\text{th}}$  percentile; high-fit:  $>75^{\text{th}}$  percentile) for males ( $n = 6,289$ ) and females ( $n = 6,171$ ), separately. Frequencies illustrate the number of subjects in each SES group who achieved a low or a high physical fitness level.

		socioeconomic status (SES)				<i>p</i> -value*
		fitness level	overall	low	middle	
20-m sprint						
male	low	26.2	26.5	26.7	25.4	.557
	high	19.0	18.0	18.8	19.9	.332
female	low	28.4	29.7	29.0	26.8	.109
	high	24.0	23.0	23.6	25.0	.358
ball push						
male	low	26.1	26.8	25.6	26.4	.668
	high	28.7	30.0	28.6	27.9	.397
female	low	20.5	20.7	19.8	21.2	.489
	high	26.9	26.2	29.0	24.7	.003
SLJ						
male	low	24.2	30.0	24.1	20.9	< .001
	high	25.1	21.4	23.4	29.2	< .001
female	low	21.4	26.3	21.3	18.5	< .001
	high	26.9	23.0	26.2	30.1	< .001
SaR						
male	low	23.9	23.9	23.8	24.1	.977
	high	29.3	31.0	28.2	29.5	.177
female	low	22.2	21.3	22.2	22.8	.581
	high	26.8	26.2	26.8	27.0	.874
star run						
male	low	25.2	28.4	23.9	24.8	.007
	high	24.2	22.8	23.9	25.9	.051
female	low	25.1	27.4	23.4	25.7	.015
	high	24.3	23.1	24.5	24.9	.474
6-min run						
male	low	24.5	25.0	25.5	23.0	.104
	high	26.9	27.8	25.5	29.2	.001
female	low	24.6	25.8	25.6	22.8	.041
	high	25.5	24.8	24.2	27.4	.037

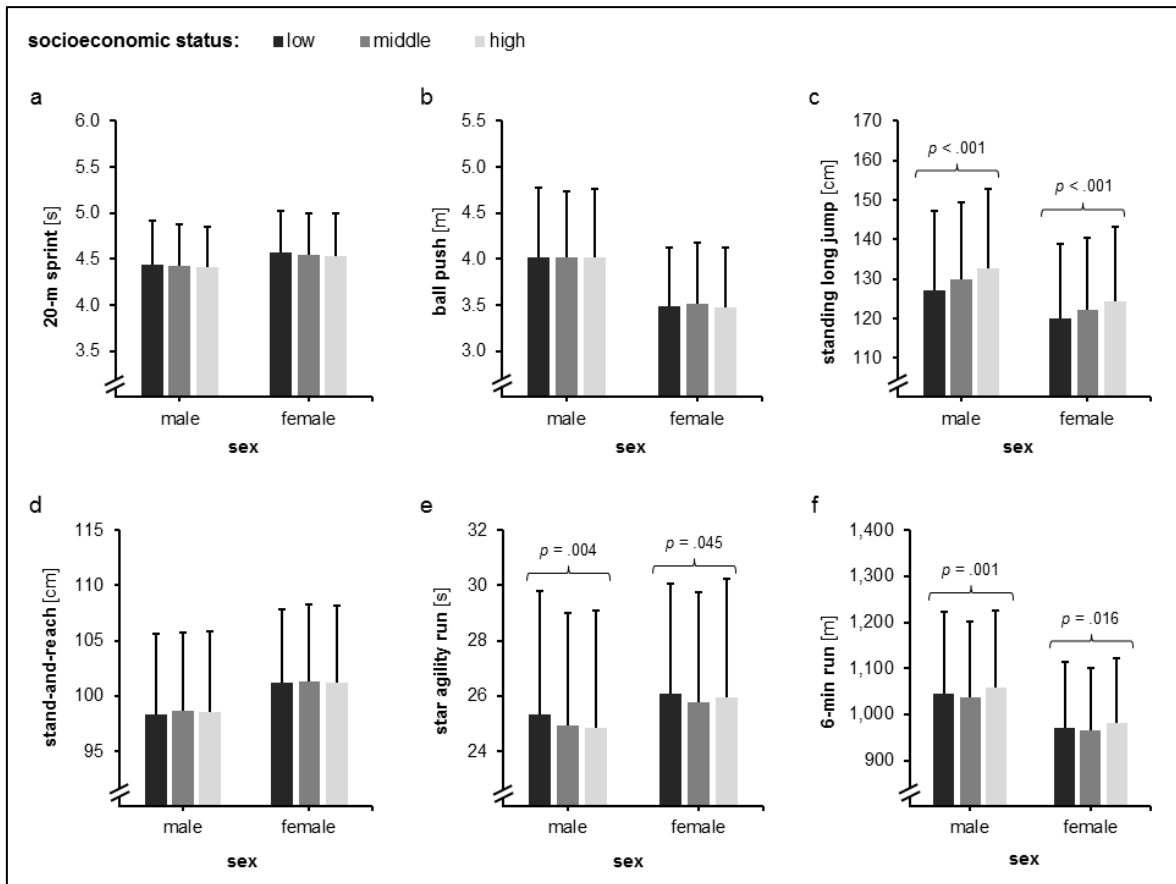
Notes. ball push = 1-kg medicine ball push test; SLJ = standing long jump test; SaR = stand-and-reach test; star run = star agility run test; \**p*-value was determined by using the chi-square test ( $\chi^2$ ).

#### *Physical fitness differences by socioeconomic status*

Our statistical analyses detected significant differences ( $p < .001$ ) in chronological age between the three SES-groups (i.e., boys and girls in the high SES-group were younger than those in the middle and low SES-groups) (data not shown). Furthermore, the number of students who actively participated in organized sports differed significantly ( $p < .001$ ) between SES-groups (i.e., boys and girls in the high [65-69%] SES-group participated

more often than those in the middle [58-65%] and low [55-64%] SES-groups). Due to the aforementioned significant differences, the subsequent ANCOVA model was adjusted for the respective confounding variables (i.e., age and organized sports participation).

Adjusted comparisons of physical fitness between SES-groups are provided in Figure 4. For boys, significant differences in physical fitness by SES were detected for the standing long jump test ( $F_{[2, 6284]} = 32.0, p < .001$ ), the star agility run test ( $F_{[2, 6284]} = 5.4, p = .004$ ), and the 6-min run test ( $F_{[2, 6284]} = 6.5, p = .001$ ). Post-hoc analyses indicated significantly better performances in the high compared to the middle (standing long jump test:  $p < .001$ ; 6-min run test:  $p = .001$ ) and the low (standing long jump test:  $p < .001$ ; star agility run test:  $p = .010$ ) SES-groups. Further, for the standing long jump test ( $p < .001$ ) and the star agility run test ( $p = .007$ ) better performances were detected in the middle compared to the low SES-group. For girls, significant differences in physical fitness between SES categories were found for the standing long jump test ( $F_{[2, 6166]} = 19.4, p < .001$ ), the star agility run test ( $F_{[2, 6166]} = 3.1, p = .045$ ), and the 6-min run test ( $F_{[2, 6166]} = 4.1, p = .016$ ). Post-hoc analyses indicated significantly better performances in the high compared to the middle (standing long jump test:  $p = .001$ ; 6-min run test:  $p = .013$ ) and the low (standing long jump test:  $p < .001$ ) SES-groups. Lastly, the middle SES-group outperformed the low SES-group in the standing long jump test ( $p = .005$ ).



**Figure 14:** Physical fitness differences in 12,460 primary school-aged children (male:  $n = 6,289$ ; female:  $n = 6,171$ ) by socioeconomic status (low:  $n = 2,699$ ; middle:  $n = 5,260$ ; high:  $n = 4,501$ ). (a) 20-m sprint test, (b) ball push test, (c) standing long jump test, (d) stand-and-reach test, (e) star agility run test, and (f) 6-min run test. Notes. *P*-values of the adjusted ANCOVA (covariates: age, organized sports participation) for comparison of physical fitness between categories of socioeconomic status.

### 6.3.5 Discussion

We investigated socioeconomic differences in physical fitness in a large sample of healthy primary school-aged children using a cross-sectional approach. Irrespective of sex, significantly higher proportions of students with high fitness levels in two out of six fitness test items (i.e., standing long jump test, 6-min run test) were found in the high compared to the middle and/or low SES-groups. This is supported by our second main finding that boys and girls of high compared to middle and/or low SES background achieved significantly better performances for measures of lower-extremity muscle strength (standing long jump test), endurance (6-min run test), and agility (star agility run test).

We hypothesized better physical fitness levels in students living in high SES communities compared to those living in middle and/or low SES communities. We can confirm our first hypothesis because the present study revealed that boys and girls of middle and/or low SES background were significantly more often classified as low fit compared to students of high SES background. In fact, a more in-depth analysis of physical fitness by SES illustrated that children from the high SES-group outperformed their

counterparts from the middle and/or low SES-groups in terms of lower-extremity muscle strength, endurance, and agility. This implies that SES seems to be an influencing factor of physical fitness in healthy primary school-aged children. This finding is in accordance with Kristensen et al. (2006) who observed a significantly better cardio-respiratory fitness level in children from high as compared to low SES-groups. In addition, our findings are partially supported by Freitas et al. (2007) who found better balance performance (i.e., flamingo stance) in children of high compared to middle and/or low SES background. Nevertheless, it has to be mentioned that the same authors reported better endurance (i.e., 12-min run), muscular strength endurance (i.e., bent-arm hang), and speed (i.e., plate tapping) performances in students from low and/or middle SES-groups as compared to those from a high SES group (Freitas et al. 2007).

With regards to our second hypothesis (i.e., SES produces sex-specific differences in physical fitness), our data cannot confirm the initial hypothesis because the factor sex did not influence outcomes in physical fitness between students from high versus middle and/or low SES communities. This result is in contrast to the studies of Freitas et al. (2007) and Bohr et al. (2013) who observed SES-related differences in physical fitness between boys and girls. More precisely, Freitas and colleagues (2007) reported significantly better physical fitness in favor of the high SES-group in boys but not in girls. Contrary, Bohr et al. (Bohr et al. 2013) reported better physical fitness performances for girls living in high SES communities but not for boys. Our findings do not comply with the results of these studies. The discrepancy in findings between studies might be explained by the fact that in the present study, rates of organized sports participation decreased to the same extent in boys and girls from the high over the middle to the low SES-group. This indicates that sex did not influence engagement in organized PA within a SES-group and therefore impeded SES-related differences in physical fitness between boys and girls. Furthermore, inconsistencies between findings may additionally be explained by the investigated cohorts (i.e., age groups). In our study, students with an age range of 10-12 years were investigated. In contrast, older students were tested by Freitas et al. (2007) (i.e., 8-18 year) and by Bohr et al. (2013) (i.e., 11-15 years). Notably, it is reported that sex-differences in PA and physical fitness (i.e., girls less active and fit than boys) are more prevalent in adolescents as compared to children (Freitas et al. 2007, Kristjansdottir & Vilhjalmsdottir 2001). Therefore, it can be argued that sex seems to play a crucial role in adolescents' physical fitness but not in children, in particular when SES is considered (Freitas et al. 2007, Bohr et al. 2013).

In the present study, organized sports participation significantly differed between students of high versus middle and/or low SES background. This might explain why students in the high SES-group showed better performances in physical fitness tests as compared to those in the middle and/or low SES groups. However, even though our analysis was adjusted for this potential confounder (i.e., organized sport participation), it seems that physical fitness is still influenced by SES-related differences in PA. This is due to the fact that adjustments were performed for organized sports participation but not for PA in general. Of note, PA is not only influenced by the single factor organized sports participation, but also by several other factors (e.g., active free play, active commuting to

school, active school breaks). In this regard, a number of studies previously illustrated a relationship between high levels of PA and high SES (Borraccino et al. 2009, Kristjansdottir & Vilhjalmsón 2001, Seabra et al. 2011). For example, Borraccino et al. (2009) investigated the influence of SES on the number of students (11, 13, and 15 years) living in 32 European countries who followed PA guidelines provided by the World Health Organization. For the majority of involved countries (24 out of 32), the relative risk of not complying with the PA guidelines (i.e., 60 minutes of moderate to vigorous PA for at least five days a week) was significantly higher in students of low and middle as compared to high SES. Further, a representative national survey of 3,270 Icelandic primary school-aged children (11-16 years) revealed that students of high SES background (i.e., parent's job included business-owners, executives, and university-educated specialists and professionals) were significantly less sedentary and more physically active during leisure time than students of low SES background (i.e., parent's job included skilled and unskilled manual workers, shermen, and farmers) (Kristjansdottir & Vilhjalmsón 2001). Lastly, Seabra et al. (2011) examined the association between SES and level of PA among Portuguese students aged 10-18 years. They found that students in the high compared to those in the low SES-group more often engaged in moderate and high levels of PA.

Numerous studies showed a positive relationship between PA and physical fitness in children (for a review see: Tremblay et al. 2011). For example, Martinez-Gomez et al. (2011) tested muscular strength (i.e., handgrip strength test, 60-s abdominal test, and standing long jump test) in 211 students (13-16 years) and monitored their PA over seven days. Linear regression analysis showed that vigorous PA was significantly and positively associated with physical fitness. A high level of physical fitness is negatively associated with various cardiovascular and fall/injury risk factors in children. In fact, Artero et al. (2011) reported that cardiorespiratory (i.e., 20-m shuttle run test) and muscular (i.e., standing long jump test) fitness were independently associated with clustered metabolic risk (e.g., waist circumference, systolic blood pressure, cholesterol, insulin resistance) in students aged 12-17 years. Furthermore, children with low leg muscle strength are more likely to sustain lower-extremity sport injuries (Knapik et al. 1991). Based on our finding of significantly lower performances for measures of endurance (6-min run test) and lower-extremity muscle strength (standing long jump test) in students from the low and middle compared to the high SES-group, it is argued that more effort is necessary to promote PA in children living in low and middle SES communities. This may result in better physical fitness and ultimately in improved health. In this regard, Bonhauser et al. (2005) conducted an intervention study to evaluate the effects of a school-based PA program on physical fitness and mental health in adolescents (~15 years) living in low SES communities. The experimental period comprised one school year and the intervention group conducted an exercise program based on students' PA preferences, teachers' expertise, and local resources. After the intervention period, endurance (Yo-Yo intermittent recovery test), lower-extremity muscle strength (countermovement jump test), and speed (30-m sprint test) performances significantly increased together with self-esteem in the intervention but not in the control group. In addition, anxiety significantly decreased in the intervention group. The authors concluded that a specifically tailored exercise program offered in a



school setting is beneficial for physical fitness and mental health in students of low SES background.

### 6.3.6 Conclusion

The present study investigated socioeconomic differences in physical fitness in healthy primary school-aged children using a relatively large sample of 12,460 boys and girls. Our data indicate that irrespective of sex, SES seems to be an influencing factor of physical fitness. Boys and girls with high fitness levels lived more often in high compared to middle or low SES communities. In addition, children of high SES background achieved better health-related fitness performances (i.e., endurance and lower-extremity muscle strength) compared to those of middle and/or low SES background. As a consequence, programs for the promotion of physical fitness with special emphasis on endurance and lower-extremity muscle strength should be particularly offered in communities with low and middle SES.

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## 7. General discussion

### 7.1 Development of PF

The results arrived from the annual longitudinal assessment of physical fitness in children from age 9 to 12 revealed in a first step that both boys and girls enhanced their performance in measures of speed (50-m sprint), muscular power (upper body: ball push, lower body: triple hop), agility (star-agility run), and cardiorespiratory fitness ([CRF], 9-min run) by age. With respect to the conducted stand-and-reach test an improvement in flexibility from age 9 to 12 was also detected in girls, whereas males' performance remained stable over time. Secondly, differences in physical fitness development were observed in as much as boys performed better than girls in proxies of CRF, agility, and muscular power of the upper body over time. Of note, analysis indicated only small (9-min run, star-agility-run) or medium effect sizes (ball push). Contrary, girls outperformed their male peers in proxy of flexibility which corresponded to a high effect size. Additionally, girls flexibility developed substantially faster compared to their male peers.

The underlying causes of the observed sex- and age-related differences in physical fitness development are mostly explained by processes of growth (i.e., increase in body size, body mass and body dimensions) and maturation (i.e., sexual, skeletal, and somatic maturity) that occurred during the transition from childhood to adolescence and thus the onset of puberty (Haywood & Getchell 2009, Malina et al. 2004). Normal pubertal development in humans begins between the ages of 9 to 13 years in girls and with approximately one year delay, between 10 to 14 years in boys (Bitar et al. 2000, Malina et al. 2004). In detail, pubertal development is related to an increase of fat free mass in both sexes, whereby the (annually) gain of fat mass is significantly higher in girls than boys. The latter is caused by higher circulating levels of estrogens or lower circulating levels of androgens in girls compared to boys. As a result, a higher percentage of muscle mass is notable in boys compared to girls, whereby girls show a lower tissue density (Bitar et al. 2000, Malina et al. 2004). These biological differences might especially account for the detected sex-differences in performance of upper-body muscular power (pro boys) as well as flexibility (pro girls).

With the exception of flexibility, the overall positive development of physical fitness within the same individuals confirms current findings of national (Woll et al. 2011), European (Castro-Piñero et al. 2009, J. Castro-Piñero et al. 2011, Gulias-Gonzalez et al. 2014, Milanese et al. 2010, Runhaar et al. 2010, Sauka et al. 2011), and international (Carrel et al. 2012, Catley & Tomkinson 2013, Tremblay et al. 2010) cross-sectional studies reporting physical fitness capacities in children of successive age-groups, in as much as physical fitness enhancements were notable in groups of increasing age for both sexes. The females' flexibility gain is of interest as cross sectional studies resumed

constant flexibility in girls during this age span (Gulias-Gonzalez et al. 2014, Runhaar et al. 2010, Santos et al. 2014, Sauka et al. 2011, Tremblay et al. 2010) or a trend towards an increase, after a phase of stability, not until the age of 12 (and subsequent years) (José Castro-Piñero et al. 2011, Catley & Tomkinson 2013). In boys, the same studies either confirm the results of the present thesis (i.e., constant flexibility mean scores) (José Castro-Piñero et al. 2011, Catley & Tomkinson 2013, Sauka et al. 2011, Woll et al. 2011) or revealed a decrease in performance (Gulias-Gonzalez et al. 2014, Santos et al. 2014).

## 7.2 Effect of living area on physical fitness development

Even if a significant number of cross-sectional studies addressed the association between living area and physical fitness in children across the globe and hence underlined the general interest in this subject, the cause-and-effect relationship between both factors has been investigated within the framework of the present thesis for the first time. Results of this investigation revealed that the physical fitness development in children from grades three to six of public primary schools in the German federal state of Brandenburg was partially affected by the environmental factor living area. Specifically, students living in urban areas showed a significantly better performance development in upper (1-kg ball push) and lower body muscular power (triple hop) when compared to classmates from rural areas. Additionally, respective analysis of individual grades (i.e. grades 3, 4, 5, and 6) indicated significantly higher values in urban than in rural sixth graders in four out of six physical fitness tests. These are the 50-m sprint, the 9-min run, and - in reference to the significantly faster performance development - the 1-kg ball push and the triple hop test. At grade three (i.e. baseline) significant physical fitness differences in terms of living area were observed only in the 50-m sprint.

### *Study comparison and associated methodological problems*

First of all, the findings of this thesis are unexpected since the cross-sectional state of research is dominated by studies which report a physical fitness benefit for rural residents compared to children living in urban areas (Adamo et al. 2011, Dollman & Norton 2002, Karkera et al. 2013, Kriemler et al. 2008, Magnusson et al. 2008, Özdirenç et al. 2005, Tambalis et al. 2011, J. H. Wang et al. 2013), closely followed by studies that resumed incongruence in terms of an unidirectional association between children's physical fitness and the living area (Chillón et al. 2011, Pena Reyes et al. 2003, Tsimeas et al. 2005, Ujevic et al. 2013, Woll et al. 2011) (see Table 3, in detail: Table 15). For instance, 8- to 9-year old Greeks who were tested within the scope of a national fitness survey outperformed their urban peers in all conducted physical fitness tests referring to the estimation of CRF (20-m SRT), muscular power (VJ, small ball throw) and speed (30-m sprint) (Tambalis et al. 2011). Similarly, a nation-wide evaluation of physical fitness in 9- to 12-year old elementary school children from Taiwan pointed out a better muscular fitness profile, i.a. determined by the SLJ test, for children living in rural when compared to urban areas, whereby pupils did not differ in measure of flexibility (SR) (J. H. Wang et al., 2013). In addition, a study by Chillón et al. (2011) characterized a prime example for studies that stressed no clear differences of superior physical fitness of children either living in urban or rural areas. In detail, the authors tested 7- to 16-year-olds from Spain for the role of living area in measures of CRF (20-m SRT), muscular fitness (HGS, SLJ, BAH, SU), speed/agility (5 x 10-m shuttle run), and flexibility (SR). In approximately half of tests rural residents showed better physical fitness (i.e. 20-m sprint, HGS, BAH) while results of the other half revealed the opposite (i.e. better performance in urban residents). Lastly, no area-related performance variations were observed for muscular power of the lower body (SLJ). Findings of these studies differ from those of the present thesis as in

particular the development of indices of muscular power has occurred faster in urban than in rural located children in the present thesis. It is further of interest that the overwhelming majority of studies addressing the association between living area and physical fitness stated better performance in school-aged children from rural areas when compared to children living in urban areas in tests of CRF (i.e. 20-m SRT, 1-mile run, 800-/600-m run) (Adamo et al. 2011, Chillón et al. 2011, Karkera et al. 2013, Kriemler et al. 2008, Magnusson et al. 2008, Ujevic et al. 2013) (Dollman & Norton 2002). Recently, Ujevic et al. (2013) revealed a better CRF level in Croatian boys (800-m run) and girls (600-m run) attending the fifth grade of schools from rural areas when compared to fifth graders from urban schools. This is in line with superior performance in the 20-m SRT of rural fifth graders compared to their urban counterparts from Switzerland (Kriemler et al. 2008). In contrast, for the German third to sixth graders of the current thesis a trend towards a faster performance development was verifiable in favour of pupils living in urban areas for the 9-min run, especially indicated by significantly higher values, than those of their rural counterparts at grade six.

Questioning why the present longitudinal findings mainly vary from cross-sectional reports results in at least two methodological issues: (1) the approach that was used to classify students into urban and rural areas (e.g. percentage of inhabitants) and (2) the economic status of the country in which the study was conducted (e.g. developing vs. advanced economy countries). Initially, both issues ought to be discussed in more detail as they impede a comparison between studies concerning the role of living area on children's physical fitness in general and with findings from the present thesis in particular. As depicted in Table 15, it has to be noted that about one third (31%) of the reviewed studies did not report how the distinction of urban and rural areas was determined (Adamo et al. 2011, Karkera et al. 2013, Özdirenç et al. 2005, Ujevic et al. 2013). The absence of such important information might lead almost inevitably to a comprehensible explanation of different findings among studies. The remaining studies reported a cut-off number of inhabitants in terms of classifying into urban and rural areas (e.g. rural  $\leq$  10,000 inhabitants) whereby only the initially named study of Tambalis and colleagues (2011) is known which clearly justified the distinction of urban and rural areas in reference to the respective national statistics report. Of note, due to a gap of stated references among all other studies it is likewise not comprehensible whether the classification of urban and rural areas is based on an official specification of residential area or whether it was merely randomly chosen according to the communities that were included in the respective study sample. With regard to the present thesis communities with more than 10,000 inhabitants referred to urban and communities with less or equal 10,000 inhabitants to rural areas. Comparably to Tambalis et al. (2011) this classification was made according to the statistics report of the German federal state in which the study was conducted. Referring to this report, the specification of the number of inhabitants that was used to classify into urban and rural communities considers important economic, health, and cultural parameters of the respective areas (e.g. offer of leisure time activities, availability of retail, hospital, and schools). Using such an approach will improve a comparison of findings on

studies conducted in different countries as well as in different federal states or regions within the same country - independently on further comprehensible differences of the cut-offs of inhabitants that distinguish between urban and rural areas. Nevertheless, it has to be mentioned that the cut-offs of area classification highly varied among studies. For example, in a study that reported national fitness survey data of Taiwanese children, the authors referred the three largest cities in the country to urban areas, each with at least 2.6 million inhabitants, while classification of rural areas was not specified (J. H. Wang et al. 2013). In contrast, Tsimeas et al. (2005) as well as Lovecchio et al. (2015) determined rural areas as communities with less than 10, 000 inhabitants, whereas urban areas were characterised by communities with at least (Tsimeas et al. 2005) or more than 10,000 inhabitants, respectively. Of interest, like Tsimeas et al. (2005) Tambalis and colleagues examined the association between living area and physical fitness in Greek school-aged children albeit in different geographic regions (i.e. one region vs. nationwide). However, the underlying specification of urban and rural areas differed among studies (i.e. rural  $\leq$  5,000 inhabitants by mean population density of  $\leq$  27 inhabitants/km<sup>2</sup>). The discrepancy of area-classification among both Greek studies might further be one of certainly potential explanations (e.g. diverse age groups) for different study findings reported, i.e. overall better fitness in rural children (Tambalis et al. 2011) vs. no clear differences (Tsimeas et al. 2005).

Picking up the interesting topic of nations' specific comparison, the difficulty that can arise from a single classification of living area by means of percentage of inhabitants should be stated with regard to the findings of the German 'MotorikModul (MoMo)', a sub-study of the representative German Child and Adolescent Health Survey (KiGGS) (Bös, Worth et al. 2009). In contrast to the present results, the authors revealed no differences between 4- to 17-year-olds living in urban and rural areas in a variety of physical fitness components, including CRF (cycle ergometer), muscular fitness (SLJ, SU), coordination (jumping site-to-site), balance (one-legged stance, balancing backwards), and flexibility (stand-and-reach) (Bös, Worth et al. 2009). Within the scope of the study residential areas with at least 100,000 inhabitants were classified as urban, whereas communities with less or equal to 5,000 inhabitants characterised as rural areas. By choosing this classification, more than one third (39%) of the communities referring to the sample of the present thesis would have not been taken into account due to their number of inhabitants being between 5,001 and 99,999. This markedly confounds a conclusive comparison between the study of the present thesis and the study of Bös et al. (2009). Furthermore, even though the 'MoMo-study' provides representative and quite topical data of German's youth physical fitness for the first time in relation to the status of living area, the corresponding informative value for the German federal state of Brandenburg to whom likewise the sample of the current thesis referred is questionable as none of the ten communities of Brandenburg that were included in the 'MoMo-study' fulfilled the urban criterion of at least 100,000 inhabitants. According to this fact, it has to be mentioned that the German federal state of Brandenburg is a mainly rural region, particularly in comparison with the remaining German federal states (n = 12) and German city states (n = 3). Statistical data from 2006 (i.e. study baseline) indicate that 70% out of 420

administrative communities of Brandenburg have less than 5,000 inhabitants, 10% between 10,000 and  $\leq 20,000$  inhabitants, 7% more than 20,000 inhabitants, and only two communities/cities have more than 100,000 inhabitants (i.e. 103,837 and 148,813 inhabitants) (Landesamt für Statistik, 2007). As a result, Brandenburg has the second lowest mean population density (86 inhabitants per square km) of all German federal states (Bundesamt für Statistik, 2015). In comparison, Germany has a mean population density of 231 inhabitants per square km. Once again, these data point out the necessity of a classification of living area on the basis of statistic reports that consider regional characteristics (e.g. high amount of usable/land areas, forest areas) and not only the number of inhabitants.

A second issue that arises from a study comparison of living area disparities is given by different development and economic status of the countries in which the studies were conducted – designated among developing and economy countries (see Table 15). In fact, there is evidence that differences in physical fitness exist in children of low- and high-income economies in general (Adamo et al. 2011, Olds et al. 2006, Tomkinson 2007). For instance, Adamo (2011) reported better performance in the 20-m SRT for rural as well as for urban Kenyan children compared to reference data derived from children living in high economy nations of Canada, USA, and Australia. Nevertheless and likewise contrasting to this thesis, Kenyan children from rural locations outperformed their counterparts from urban areas. Furthermore, the territorial distinction of urban and rural areas of development countries is often associated with socioeconomic, nutritional, health care, and educational inequalities between both (Andrade et al. 2014, Machado-Rodrigues, Coelho, et al. 2012, Pena Reyes et al. 2003). For example, Andrade et al. reported that the estimated prevalence of poverty (derived by respective national statistics report) was substantially higher in rural (93%) when compared to urban areas (2%) included in the Ecuadorian sample of 11- to 16-year-olds. Basing on the knowledge of this socioeconomic disparity and the evidence of an inverse association between physical fitness and socioeconomic position (see 7.4 in detail) it seems not surprising that the authors observed better performance in urban dwellers.

Beside a better status of nutrition and health care in urban areas, studies conducted in development countries revealed that urban children and adolescents were significantly taller and heavier than their classmates from rural areas (Andrade et al. 2014, Karkera et al. 2013, Pena Reyes et al. 2003). Furthermore, several studies likewise conducted in developmental countries also reported higher scores of BMI and sum of skinfold thickness in children from urban areas (Adamo et al. 2011, Karkera et al. 2013, Özdirenç et al. 2005). This finding was mostly linked with inferior physical fitness of the rural cohort when compared to their urban peers. It must be mentioned that strong socio-cultural beliefs do exist in many developing countries that perceive 'roundness' or obesity as something to be revered and a sign of economic wealth and prestige (Adamo et al. 2011). In contrast, advanced economy countries (e.g. USA, Canada, Italy) frequently observed that children and adolescents living in rural environments had a more unfavourable body composition than urban dwellers (Bertoncello et al. 2008, Bruner et al. 2008, Joens-Matre et al. 2008, Liu et al. 2008, Tambalis et al. 2011). However, within the present thesis, conducted in a major advanced economy country, no area-related differences in annual status of body



height, body weight, and BMI and the development of these parameters (i.e. grades 3 to 6) have been detected.

Of note, in the course of urbanisation the urban industrial way of life, economic systems, and types of living situations spread across rural environment of advanced economy countries, too (Bähr 2011). This process also caused that former common or at least possible disparities between urban and rural environments levelled down in these countries. For instance, access to media like internet and television, that foster sedentary habits, is likewise present in rural areas of advanced economies as well as in countries with a high degree of industrialisation and/or adoption of a western lifestyle (Özdirenç et al. 2005). Thus, it should not be surprising that studies continuously reported equal times of television watching and computer playing for children living in urban and rural locations (Dollman & Norton 2002, Joens-Matre et al. 2008, Kriemler et al. 2008, Özdirenç et al. 2005, Springer et al. 2009)

**Table 14.** Living area comparison: characteristic of studies<sup>[1]</sup> according to geographic area, development and economy status, living area classification, anthropometry characteristics, and physical fitness.

reference/ country	region <sup>[2]</sup>	national status of development <sup>[3]</sup> and economy <sup>[2]</sup>	living area classification	anthropometry: U vs. R	<sup>[3]</sup> physical fitness: U vs. R
Dollman & Norton Australia (south) (2002)	Australia	advanced economy; high income	U ≥ 20,000 inh.; R < 5,000	no differences in BH, BM, BMI, and WHR	if, then pro R
Wang et al. (2013), Taiwan	East Asia & Pacific	advanced economy Upper middle income	U ≥ 2.6 million inh. (i.e., the three biggest towns in country)	not reported	if, then pro R
Karkera et al. (2013), India	South Asia	developing country; lower middle income	not reported.	U: higher values of BH, BM, and BMI	if, then pro R
Adamo et al. (2011), Kenya	Sub-Saharan Africa	developing country; low income	not reported.	U: higher values of BMI, WC, and SFF	if, then pro R
Özdirenc et al. (2005), Turkey	Europe, Central Asia	developing country; upper middle income	not reported.	U: higher values of BMI and SFF	if, then pro R
Tisneas et al. (2005), Greece	Europe (south east)	advanced economy; high income	U > 10,000 inh. (sample: ~70,000 inh.); R < 10,000 inh. (sample: < 2,000 inh.)	no differences in BH, BM, and BMI	no differences
Tambalis et al. (2011), Greece	Europe (south east)	advanced economy; high income	based on National Statistics Service (2001): R < 5,000 inhab. and mean population density of ≤ 27 inh./km <sup>2</sup>	U: higher values of BH; R: higher values of BMI	pro R
Ujevic et al. (2013), Croatia	Europe (south)	advanced economy (since 2011); high income	not reported	U: higher values of BH	no clear differences
Lovecchio et al. (2015), Italy/ Croatia	Europe (middle)/ (south)	Italy: major advanced economy; high income	U ≥ 10,000 inh.; R < 10,000 inh.	no differences in BH, BM, and BMI for total sample	pro U: adolescence
Bös et al. (2009), Germany	Europe (middle)	major advanced economy; high income	U ≥ 100,000 inh.; R ≤ 5,000 inh.	not reported	no differences

*Continued*

**Table 15: –Continued**

reference / country	region <sup>[2]</sup>	national status of development <sup>[3]</sup> and economy <sup>1/2]</sup>	living area classification	anthropometry	Physical fitness: U vs. R
Golle et al. (2014), Germany	Europe (middle)	major advanced economy; high income	U > 10,000 inh.; R ≤ 10,000 inh.	no differences in BH, BM, and BMI	U: better development of PF; better status of PF
Chillon et al. (2011), Spain	Europe (south west)	advanced economy; high income	U ≥ 100,000 inh.; R < 10,000 inh.	U: higher values of BM, BMI and sum of SFF	no clear differences
Andrade et al. (2014), Ecuador	Latin America & Caribbean	developing country; upper middle income	U = 505,000 inh.; R = 15,000 inh.;	U: higher values of BH and BM;	pro U: adolescence
Pena Reyes et al. (2003), Mexico	North America	developing country; upper middle income	not specified U: 16,279 inhabitants	U: higher values of BH and BM	no clear differences

*Notes:* <sup>[1]</sup> inclusion criteria: published between 01/2000-07/2015 and reporting data of both sexes for at least three physical fitness tests <sup>[2]</sup>region/<sup>[2]</sup>economy status : based on the classification of The World Bank (Bank 2015); <sup>[3]</sup>developmental status: refers to the Development Assistance Committee- (DAC) list of recipients of Official Development Assistance (ODA) of the Organisation for Economic Co-operation and Development (OECD) (Development 2014) and the definition of major advanced economies by International Monetary Fund (IMF) (IMF 2015); <sup>[3]</sup>economy status: based on the classification of The World Bank (Bank 2015); inh. = inhabitants; R = rural; U = urban; BH = body height; BM = body mass; SSF = sum of skinfold thickness; WHR = waist-to-hip-ratio; PF = physical fitness.

*Interpretation of findings*

With respect to the former paragraph, the novel findings of the present thesis can most likely be explained by children's organised physical activity behaviour and associated regional specificities. Firstly, the observed (partial) better physical fitness development in children living in urban areas might be substantially caused by differences in sports club participation between both area groups. While every third children (36%) living in an urban area continuously participated in a sports club during the time frame of grades three to six, a continuous sports club participation was only observed in every fifth children from a rural residence (20%). This discrepancy in favour of a higher likelihood of being involved in a sports club in urban residences was further noticeable in analysis of annual rates of membership. At all grades, rural children were less often members in a sports club when compared to urban peers whereas differences among groups increased particularly from grades three to four (from 5 to 10%) and afterwards remained stable (8-11%). Studies investigating the association between children's physical fitness and sports club participation clearly resumed that children participating in a sports club have superior levels of physical fitness when compared to non-participants (Ara et al. 2004, Vandorpe et al. 2012, Zahner et al. 2009). In addition, findings of the present thesis also show that continuous participation in a sports club positively affects the development of lower body muscular power in children aged 9 to 12 (see chapter 7.3).

It is likely that the smaller percentage of sports club members living in rural areas is highly associated with a decreased number of sports clubs in these areas and hence the possibility to take advantage of this offer. This assumption is supported by the practiced sports disciplines that were reported among the club members from urban and rural areas. While sports club members from urban areas participated in 27 different sports the variation was significantly lower among rural members with a number of 11. The discrepancy of sports club facilities in rural environment is intensified when referring to statistical data of the federal state sports association (LSB BB 2013) that registered the amount of sports clubs with at least one member aged 7 to 14 for each community of the federal state. In 2006 (i.e. baseline) 4 to 72 sports clubs (mean 38) in urban communities that were included in the study of the present thesis listed 7- to 14-year olds as present members whereas only one to six sports clubs (mean 4) among rural areas had members of this age group. By means of a limited offer of sports clubs in rural areas it is not surprising that their under-age dwellers were less frequently members.

Data derived from a study of 13- to 19-year-olds living in urban and rural areas of the same federal state like children from the sample of the present thesis confirm that living in rural environments indicate a disadvantage for youth's participation in a sports club (J. Baur & Burrmann 2000). Baur and Burrmann found that adolescents living in urban areas of over 10,000 inhabitants were more often members in a sports club when compared to peers living in rural areas with a population of less or equal 10,000. Only one study in children is known that also investigated the relationship between sports club participation and living area, whereas living area referred to the community in which children attend school (Bös et al. 2002). Taken into account that Bös and colleagues (2002)

did not report how residential area/school area was defined, nevertheless, the study findings provide an interesting comparison as the sample includes about 1,500 first to fourth graders of six different German federal states spread throughout Germany (i.e. north to south, east to west). Bös et al. (2002) noted no significant differences in the percentage of sports club participation in children from urban and rural schools, but they observed that the percentage of pupils playing outside every day was significantly higher among those attending rural schools - a finding that should be taken in mind when discussing disparities between urban and rural environments, particularly in children. With respect to potential fitness gains of children living in rural areas, it is commonly argued that rural areas facilitate unstructured physical activity by means of more provision of safe open space (Loucaides et al. 2004, Ogunleye et al. 2011). According to this, several studies revealed that children living in rural areas showed higher amounts of playing outside (Bös et al. 2002, Ferreira et al. 2007, Loucaides et al. 2004, Özdirenç et al. 2005, Sandercock, Angus, et al. 2010) and that playing outside (in an unstructured frame) is positively associated with children's physical activity (Ferreira et al. 2007). On the other side, living in large cities and metropolis is linked with factors of heavy traffic, crime, and the absence of safe spaces for children's play in the open air that bring to light the typical urban-rural contrast. This contrast introduces a second possible explanation for the investigated faster development of physical fitness in urban children from the sample of the present thesis. It can be suggested that the demographic characteristics of the federal state of Brandenburg and its urban communities diminish commonly stated disparity between urban and rural areas in terms of children's opportunities for free and safe play for the present sample. In detail, as mentioned in the previous chapter, Brandenburg is a rurally shaped federal state. The three largest cities within the present sample, simultaneously of the federal state, had a total population of about 75,000, 100,000 and 150,000 inhabitants. The remaining three urban areas had approximately 12,000 to 29,000 inhabitants. The remaining three urban areas had approximately 12,000 to 29,000 inhabitants.

In comparison to a study by Ortlieb et al. (Ortlieb et al. 2013) which investigated the amount of time playing outdoors in relation to population size in four German villages and cities it can be revealed that urban areas included in the present thesis would clearly referred to rural areas. Ortlieb et al. (2013) found that time playing outdoors was significantly higher in the two rural areas with a population size of approximately 25,000 and 60,000 inhabitants as compared to both urban areas that had about 556,000 and 1,5 million inhabitants. Thus, it can be further assumed that children living in present urban areas are not as much confronted with high traffic jam, hazardous city districts, and the absence of cycling paths and safe and open spaces that negatively affect their free play outside and overall daily physical activity as it is reported for large cities and metropolis.

This assumption is, not least, confirmed by studies using a trilateral division of area of living to investigate the association between living area and physical activity patterns (e.g. free play) (Joens-Matre et al. 2008, Ogunleye et al. 2011, Springer et al. 2009). For instance, in a sample of 4th-, 5th-, and 6th-grade students from Iowa (USA), Joens-Matre et al. (2008) distinguish the area of residence by *urban* (> 250,000), *suburban* (>20.000-250,000), and *rural* (20,000). According to these population cut-offs, urban communities

within the study of the present thesis would be referred to suburban areas and in two cases to rural ones. Joens-Matre and colleagues (2008) observed that pupils from suburban and rural areas showed equal amounts of physical activity and both groups were significantly more active than youth living in urban areas, particularly during lunchtime and after school.

Returning to the observed differences in children's (continuous) sports club participation, it is important to note that organised sports participation accounts for a high amount of individual's moderate to vigorous physical activity. (Ortlieb et al. 2013, Silva et al. 2013, Vilhjalmsson & Kristjansdottir 2003, Wickel & Eisenmann 2007). Especially moderate to vigorous intensities of physical activity are named for positively affect individual's physical fitness (Janssen & Leblanc 2010, Moore et al. 2013). A fact that might retrieves itself in the faster performance development in measures of muscular fitness. Niclasen et al. (2012) examined the association between physical activity pattern in 11- to 17-year-olds from Greenland and structural characteristics (i.e., availability of sports facilities and sports clubs with child members) of youth' area of residence. Even though the authors did not focus on living area comparison results are of importance as they stressed the potential disadvantage of rural areas with decreased facilities on their residents' PA. The authors found that access to indoor sports facilities itself had a positive association with youth' high vigorous physical activity. In addition, already presence of sports clubs with child members was positively associated with high VPA.

It is further known that during childhood and particularly in transition to adolescence organized physical activities (e.g., in sports clubs) gain in importance, even to the detrimental of free play outside (Sallis et al. 2000, Sandercock, Angus, et al. 2010). Therefore, living in rural areas might become a more unfavorable and perceivable factor in physical fitness status and its development in older children and adolescents when compared to urban peers and (partially) explain the observed differences in physical fitness development between both area groups. Specifically, while performances in physical fitness tests did not differ markedly between both area groups in grade 3 (i.e. baseline) a drift-apart in performances in favour of pupils living in urban areas was observed from grades five to six in particular. A few cross-sectional studies, also conducted in advanced economy countries, support this assumption as they observed that older children and adolescents living in urban areas showed better physical fitness than rural peers – however, noticing that those studies did not investigate physical activity habits and hence the assumed positive effect of sports club participation. Recently, Levecchio et al. (2015) resumed overall better physical fitness in urban dwellers when compared to rural peers in a transnational sample of about 14,700 Italians and Croatians aged 11 to 14. Students were tested for their muscular power (SLJ), muscular endurance (SU), and flexibility (SR). In addition, results of a study by Sandercock and associates (2010) extended the picture of better physical fitness in adolescents living in urban areas by component of CRF (20-m SRT). Of interest, while the authors revealed no area-related differences in CRF of 10- to 12-year old children from England, CRF (20-m SRT mean z-score) of 13- to 15-year old urban residents (urban > 10,000 inh.) of the same sample (i.e. adolescents' cohort) was significantly higher when compared to rural peers. Additionally, Sandercock et al. (2010)

reported that children and adolescents (i.e. 10-15 years) living in rural areas were significantly less likely to meet criterion-based cut-off points for CRF (i.e. Healthy Fitness Zone of Fitnessgram). The observed higher risk for cardiovascular disease (CVD) in rural residents also addressed an important aspect in terms of interpreting the findings derived from the current thesis. Thus, one must question to what extent the inferior physical fitness status (and underlined fitness development) at the transition to adolescence in rural residents might show a health impairing disadvantage referring to 'special need'. Or might the findings 'only' highlight a 'far above average' physical fitness level/ development of urban dwellers – maybe due to better access to sports clubs. As discussed in the previous chapter (7.1) the specific of physical fitness tests applied as well as the lack of criterion-based norm values make it difficult to clarify this question. The comparison among findings of the present thesis (i.e. studies 1, 2, and 3) and previously published studies and norm values (see chapter 7.1 and 7.4) stated that 9- to 12-year olds of the present thesis, including the children from rural areas, showed at least an average level of physical fitness in comparison with peers from overall Germany and other nations. Particularly the comparison with studies that used the 9-min run test to estimate children's CRF outlined that the children tested within the frame of the current thesis showed higher mean values. Of course, this study comparison of mean values allowed no interpretation of individual's health-related physical fitness status. Actual criterion-based norm values for the 9-min run were reported by Bergmann et al. (2010). By mean of a sum score of total cholesterol and systolic and diastolic blood pressure derived from a sample of 7- to 12-year old boys and girls from Brazil the authors computed cut-off points for an increased chance of cardiovascular risk. Concerning these cut-offs respective analysis for the sample of the present thesis showed an annually (i.e. grades 3 to 6) higher percentage of children from rural areas with an increased risk of CVD. In detail, the amount of children that did not reach the cut-off points ranged from 9% to 18% among the rural group and 5% to 12% among the urban one whereby the percentage particularly increased from grades five to six in both area groups. Of interest, the amount of children that continuously did not reach the cut-off points was three times higher in rural children (6%) than in urban peers (2%). Even though all group comparisons were not statistically significant (chi-square test [ $\chi^2$ ]:  $p > .05$ ) the higher amount of rural residents with increased risk of CVD indicates that the higher performance of urban residents in the 9-min run test is associated with a better CVD-risk profile. Therefore it should be the aim to reduce the observed area-related differences in children's physical fitness development by promoting children living in rural areas in their physical fitness development.

### 7.3 Effect of sports club participation on physical fitness development

Concentrating on school-aged children's physical fitness and its promotion will be inevitably stressed the impact of sports clubs participation within this topic. This association is not surprising considering that sports clubs in Germany are the primary setting in which children get physically active during their leisure time and hence can enhance and maintain their physical fitness. The participation in a sports club (at least for a short period of time in life) is listed in the biography of the overwhelming amount of German youth. Statistical data of the German Olympic Sports Federation highlights that about three quarters (72%) of German children aged 7 to 14 years are current member in a sports club (DOSB 2014). In addition, within the scope of a ten-year longitudinal study, including about 1,600 students from a big city in Germany, Gerlach and Brettschneider recently reported that only 20% of students were never enrolled in a sports club during their youth (i.e., 7-17 years) (Gerlach & Brettschneider 2013). It is thus astonishing that research has hardly devoted to the role of sports clubs on children's physical fitness. In particular the effect of regular sports club participation on children's (and adolescents') physical fitness development is unexplored. Nevertheless, the few studies investigating the association between physical fitness and the status of sports club participation by means of cross-sectional approach continuously emphasized the physical fitness gain of children that participating in a sports club as compared to non-participating peers. For instance, sports club members across a sample of about 1,100 second graders from German primary schools outperformed their classmates not involved in a sports club in measures of CRF (6-min run), upper-extremity muscular power (medicine ball throw), coordination (throw-and-turn), and balance (one-leg balancing) (Drenowatz et al. 2013). No meaningful performance disparities between both groups were noted for proxies of speed (20-m sprint) and agility (obstacle run). However, cross-sectional based findings regarding a better physical fitness level of children participating in a sports club as compared to non-participants are always linked to a potential selection bias that refers to the question 'What was first, the sports club membership (that positively affects the physical fitness level observed) or the better physical fitness level in comparison to non-participants (that encouraged to participate in a sports club, e.g., due to assumed success in sports competitions)?'.

Taking up this question, the findings of the present thesis revealed for the first time that continuous participation in a sports club has a positive impact on the development of specific physical fitness components in children. In fact, it could be shown that regular participation in a sports club in third to sixth graders refers to a significant better fitness development of children's lower body muscular power (triple hop) as compared to children that were never enrolled in a sports club during the investigated four-year period. Furthermore, a trend was observed regarding a better fitness development of CRF (9-min run) in favor of children that continuously participated in a sports club.



Even though no previous longitudinal studies examined the effect of sports club participation on a wide range of physical fitness components in children, recently, Vandorpe et al. (2012) analyzed the influence of sports participation on the development of gross motor coordination level in initial six- to nine-year-olds from Flanders over three years (i.e., three measurement points during two chronological years). The gross motor coordination level was defined by a sum score of a test battery including four test items (i.e., motor quotient of balancing backwards, moving sideways, jumping sideways, and hopping over). In contrast to the present thesis, sports participation was classified in three groups: no participation, partial participation, and consistent participation. Concerning to this classification and the missing interaction effect of time x sports club participation, Vandorpe et al. (2012) resumed that sports club participation over time did not influence the time course of motor coordination development. However, for all three measurement time points motor coordination level was significantly lower in the non-participation group than the partial-participation group and the consistent-participation group over time. In addition, children that reported to be consistently engaged in organized sports over the study period outperformed the partially-participating peers (Vandorpe et al. 2012). The observed main effect of sports club participation on children's performance in coordination is in line with results of the present thesis as higher performances of continuous sports club members were found in measures of lower- and upper-body muscular power (triple hop, 1-kg ball push), speed (50-m sprint), agility (star-agility run), and flexibility (stand-and-reach) when compared to non-participants over time. Thus, the present findings likewise confirm the cross-sectional state of research.

The (partially) better physical fitness development in sports club participating children within the study of the present thesis might be highly caused by the formal and structured organizational frame in which physical activity takes place - referring to physical exercise and associated higher amounts of moderate to vigorous intensities.

Several studies revealed that the engagement in a sports club markedly contributes to youth's physical activity (Machado-Rodrigues, Coelho e Silva, et al. 2012, Ortlieb et al. 2013, Saar & Jurimae 2007, Silva et al. 2013). For instance, Ortlieb et al. (2013) showed that 9- to 10-year-olds from Germany that did not participate in sports clubs had less amounts of daily vigorous physical activity as compared to their peers that participated in a sports club. Additionally, overall physical activity of non-participants was lower than in participants during the winter season. By recording 6- to 12-years old boys' physical activity via accelerometer, Wickel and Eisenmann (2007) revealed that organized sports participation covered almost one quarter (23%) of the total daily moderate to vigorous physical activity (MVPA). Additionally, the authors noted that during a non-sports day, boys spent significantly more time in sedentary activities. The latter is in line with findings of 8- to 10-years old boys and girls from England (Pearce et al. 2012). Children who spent more time in out-of-school sports clubs had likewise lower percentages of time spent in sedentary behaviors. At least, Saar and Jurimae (2007) confirm the positive association between sports club participation and physical activity for the cohort of adolescents. The authors found a higher physical activity index in sports club members as compared to non-members, reported in a sample of 11- to 17-year-olds from Estonia.

In this regard, sports clubs ought to be invoked as a potentially important means to ensure health-related sufficient amounts of regular physical activity in youth. Literature resumed that a high percentage of children did not meet the recommendations of the WHO of at least 60 minutes of MVPA a day in 5- to 17-year-olds (WHO 2010). For instance, data from a German sub-sample of the international HBSC-study (HBSC: health behaviour in school-aged children) outlined that in 11- to 15-year old Germans only 14% of girls and 20% of boys met the recommendations of the WHO (HBSC-Team Deutschland 2011). Referring to recently published recommendations for promoting physical activity for children and adolescents in Germany the observed low rates in German youth are of public health concern. The consensus statement of German researchers proposes an amount of 90 minutes a day of physical activity (i.e., no specification of intensity) or at least 12,000 steps daily.

With respect to the outlined physical activity recommendations as well as the frequently reported decline of physical activity on the transition from childhood to adolescence (Malina & Katzmarzyk 2006, Riddoch et al. 2004), a regular participation in sports clubs might become a crucial source of physical activity particularly in late childhood and early adolescence (Basterfield et al. 2015). For instance, a longitudinal observation of 13-year-olds over a 15-year time period outlined that in the course of time, organized sports activities became a more important contributor of weekly habitual PA (van Mechelen et al., 2000). In addition, even though researchers detected a considerable decrease in time spent on non-organized PA over the study period, amount of PA within the frame of organized sports activities remained stable in both sexes up to age of 27 years.

Recently, Basterfield and colleagues (2015) reported that sports club participation at age nine was highly predictive of participation at age twelve, independent of sex and socioeconomic status. Of note, a predictive function of sports club participation on gross motor coordination in six- to ten- year-olds over a two-year time period was likewise observed by D'Hondt et al. (2013).

In addition, it is evident that organized sports participation (e.g., in sports clubs) during childhood and adolescent is a significant predictor of young adults' participation in sports and physical fitness activities (Kjonnixsen et al. 2009, Perkins et al. 2004). Due to the fact that the present thesis revealed, on the one side, that regular sports participation positively affects children's physical fitness in specific health-related components and, on the other side, that also a selection bias cannot be ruled (i.e., especially fit children decide to enroll in a sports club) emphasis should be placed on promoting children with low physical fitness to enroll in sports clubs. With regard to the link between physical fitness and several health-related outcomes in youth (Artero et al. 2011, Chen et al. 2006) as well as the tracking of physical fitness from youth to adulthood (Ruiz et al. 2009, Twisk et al. 2000), more emphasis should be laid on establishing sports clubs as an easy and attractive means to promote health-enhancing daily physical activity as well as physical fitness.

Of note, the promotion of children's physical fitness and habits of regular participation in physical activity present only two of many objectives of sports clubs. Youth' sports club participation further contributes to (1) enhancement of individual's health-related quality of life, confidence, self-esteem, and social interactions (Carreres-

Ponsoda et al. 2012, Spengler & Woll 2013) as well as (2) learning of values associated with sportsmanship, fair play, pro-social behaviour and personal and social responsibility (Coatsworth & Conroy 2007, Malina 2009).

### *Limitations*

Due to the fact that the study encompassed children that are still in process of physical growth and maturity one limitation is that no indicators of growth and maturation were included. In addition, the selection criteria underlined in the study method (i.e., regularly active sports participants vs. never active sports participants) might intensify the diversity of growth and maturation in children that is present in general. For instance, Drenowatz et al. (2013) stated lower rates of sports participating in early maturing boys as compared to normal and late maturing peers. This is in line with a recently published report of Manna (2014). The author resumed that early maturing girls undergo a socialization process which does not motivate them any more to excel in physical exercise and hence sports clubs. On the other side, late-maturing girls tend to be socialized into sports participation that refers to the apparent delay in maturity in sports where females who maintain preadolescent physique seem to have an advantage (Manna 2014). A fact not at least displaced because of typical talent identification processes that are linked to a sports club participation in specific sports like gymnastic, artistic and dancing. Of note, the opposite is given in sports where (above average) body compositions indicate a performance gain, e.g. basketball and rowing. A further limitation might be that no data regarding children's socioeconomic status (SES) were considered. It is documented that children with low SES are less often enrolled in a sports club/ school sports club (Seabra et al. 2008, Vandendriessche et al. 2012). Similar, study 3 within the present thesis detected that sports club participation decreased with decreasing SES. As intensively discussed in the present thesis, low(er) SES is linked with less physical fitness and with more unfavourable health outcomes in body composition (e.g., obesity), diet, as well as sedentary- and physical activity behaviours. Taking into account that these indices are related to individual's physical fitness (and likewise track over times), it is not implausible that they overdraw/distorted the observed association between sports club participation and physical fitness development in children. Thus, future studies should (at least) consider the inclusion of child's SES. Further limitations include the necessity of a parental self-report measure of sports club participation, with the potential problems of recall bias.

### *Limitations*

Due to the fact that the study encompassed children that are still in process of growth and maturation, one limitation is that no indicators of growth and maturation (e.g. Tanner stages) were included. In addition, the selection criteria underlined in the study method (i.e., regularly active sports participants vs. never active sports participants) might intensify the diversity of growth and maturation in children that is present in general. For instance, Drenowatz et al. (Drenowatz et al. 2013) stated lower rates of sports participating in early maturing boys as compared to normal and late maturing peers. This is in line with a recently published report of Manna (Manna 2014). The author resumed that early maturing

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## 7.4 Role of socioeconomic status on physical fitness

Social inequality as determined by the socioeconomic status (SES) extends through many areas of children's life. For instance, knowing about the national specific of education systems, the first PISA study in 2000 (PISA: Programme for International Student Assessment) i.a. reported that Germany, more so than any other OECD country (OECD: Organisation for Economic Co-operation and Development), suffered the strongest links between educational success (e.g., reading- and mathematical literacy) and social origin (i.e., SES) (Stanat et al. 2002). In accordance, the annual German 'Equity and Excellence Monitor', first published in 2012, resumed a continuingly pronounced dependency between children's educational success and their SES (Berkemeyer et al. 2012, Berkemeyer et al. 2014, Berkemeyer et al. 2013). Furthermore, several studies revealed that low SES in children is associated with more unfavorable profiles of health-related components like overweight/ obesity (Kleiser et al. 2009, Noh et al. 2014), eating habits (Janssen et al. 2006), and sedentary- as well as physical activity (PA) behavior (Borraccino et al. 2009, Fairclough et al. 2009, Gorely et al. 2004).

With respect to the health determinant physical fitness, a comparatively small amount of studies investigated to what extent a relation to SES exists in school-aged children. Herein it has to be mentioned that several studies are limited in focusing on measures of CRF. For example, Kristensen et al. (2006) compared CRF (VO<sub>2</sub>max by progressive maximal cycle ergometer test) between eight- to ten-year old third graders with high and low SES. The authors stated significantly higher mean values of Vo<sub>2</sub>max in boys and girls of high SES compared to counterparts of low SES. Furthermore, the authors generated sex- and age-specific quartile cut off points to address low physical fitness in terms of lowest performance quartile. As a result, the percentage of children with low CRF (i.e., lowest sex- and age-specific quartile) was significantly higher in boys with low SES as compared to children with high SES (32% vs. 16%), whereas percentage of low fitness girls only tended to be statistically different according to SES, nevertheless, with meaningful differences in percentages (low: 31%, high: 21%).

The findings of the present thesis revealed in a first step that third graders from schools in communities of high SES achieved more often the high fitness level in proxies of CRF (6-min run) and lower-body muscular power (SLJ) as compared to children from communities of middle and low SES. This is supported by the second main finding that boys and girls of high compared to middle and low SES background achieved significantly better performances for measures of lower-body muscular power (standing long jump test) and (6-min run test; only middle SES). Performance of boys and girls of low SES was likewise significantly poorer in comparison with classmates of middle SES. In addition, boys of high SES outperformed their peers of low SES in measure of agility (star agility run test). Respective findings of SES-related performance disparities were not observed for remaining physical fitness tests that were conducted to estimate children's capability in physical fitness components of speed (20-m sprint), upper-body muscular power (ball push), and flexibility (stand-and-reach).

Nevertheless, the present results imply that SES seems to be an influencing factor of health-related physical fitness (i.e., CRF and muscular power) in primary school-aged children. This finding is in line with previously published studies reporting a positive association between physical fitness and children's socioeconomic background (Bös, Worth et al. 2009, Mutunga et al. 2006, Vandendriessche et al. 2012). Particularly, a recently published study by Klein et al. (2015) confirms the present findings. More specifically, Klein et al. (2015) investigated the association between SES and physical fitness components of CRF (6-min run), lower-body muscular power (SLJ), and speed (20-m sprint) in about 1,400 first-, fourth-, seventh-, and tenth- graders from a cohort-specific representative sample of a German federal state (Saarland). The authors revealed that pupils of high SES exhibit a better physical fitness compared with that of lower SES. Due to the fact that the study by Klein and colleagues (2015) the same fitness tests as conducted in the present sample (i.e., 6-min run, SLJ, 20-m sprint) of third graders (7-10 years) it might be of interest to take a deeper insight of the results for the fourth grade students (9-11 years). Even though Klein et al. (2015) did not test for significance within single grades performances (e.g., analysis of variance), mean values of SES-groups for the SLJ test and the 6-min run test highlighted better performances in the high SES-group (boys: 149 cm/ 1117 m; girls: 144 cm/ 1058 m) as compared to middle (boys: 141 cm/ 1072 m; girl: 139 cm/ 1011 m) and low SES-group (boys: 141 cm/ 1040 m girls: 138 cm/ 976 m). Within the present thesis results of both tests pointed out to be significantly better in favor of children with high SES and further the percentage of high fit children was higher in the high SES-group than the middle and/or the low SES-group for both tests

Besides the aim to examine potential differences in physical fitness according to SES, a second objective of the present thesis was to investigate whether the relation between physical fitness and SES depends on sex. Previous studies reflected inconsistency according to this issue. For example, Bös et al. (2009) revealed that SES primarily influenced physical fitness in females but to a lesser extent in males. Within the framework of the German 'MoMo'-study (as already cited in chapter 7.2) girls of the high SES-group aged six to 13 years achieved significantly higher values in PU, SLJ, flamingo balance, balancing backwards, jumping sideways (only in 11- to 13-year olds), and SR in comparison to peers of the low SES-group, whereas no SES-related performance differences were observed in cycle ergometer test (Bös, Worth et al. 2009). Depending on age-group, boys in the high SES-group only outperformed their counterparts in the low SES-group for SLJ (only 6- to 10-year olds) and cycle ergometer (only 11- to 13-year-olds). The same sex-specific pattern (i.e., stronger relation in girls) was more recently reported by Vandendriessche and colleagues (2012) in a sample of 6- to 11-year-olds. Children were tested for proxies of motor coordination (i.e., 'Körperkoordinationstest für Kinder', including jumping sideways, moving sideways on boxes, hopping for height on one leg, and balancing backwards), CRF (20-m SRT), and neuromotor fitness including muscular strength (HGS), power (SLJ, counter movement jump), muscular endurance (knee push-ups [PU], SU), speed/agility (10 × 5-m shuttle-run), and flexibility (sit and reach [SR], shoulder). While in boys significant performance differences by SES were only present for the SU-test in favor of the high SES-group, girls of high SES outperformed

their peers of low and middle SES in proxies of coordination, CRF, speed/agility, abdominal muscular endurance (SU, only low SES), and shoulder flexibility.

In contrast to previously published studies, within the study of the present thesis the factor sex did not influence outcomes in physical fitness between students from high versus middle and/or low SES communities. One reason might be the equal pattern of organized sports participation in both sexes. More specifically, rates of organized sports participation decreased to the same extent in boys and girls from the high over the middle to the low SES-group. This indicates that sex did not influence engagement in organized physical activity within a SES-group and therefore counteracted potential SES-related differences in physical fitness between boys and girls.

In search for reasons of better physical fitness in children from high SES background as compared to children of middle and/or low SES background potential disparities between SES-groups in organized and informal physical activity are of further significance. Like mentioned above, organized sports participation in boys and girls of high SES was significantly higher as compared to sex-specific peers of middle and low SES. In this regard it has to be noted that separate analysis for both indicators of organized sports participation revealed that participation differences referred to SES-related variations in rates of sports club participation, whereas participation rates in extra-curricular physical education classes were approximately equal across SES-groups in both sexes. As outlined in the previous chapter (7.3), sports club participation positively affects children's physical fitness. A similar association between participation extra-curricular physical education classes and physical fitness is not known. It might be that particularly the higher amount of sports club participants within the high SES-group contributes to better physical fitness of this group and hence the statistical adjustment to organized sports participation was not sensitive enough.

Of note, besides organized sports participation, several other activity habits contribute to children's overall PA (e.g., active free play, active commuting to school). In this regard, the positive association between PA and SES in children is well documented (Borraccino et al. 2009, Federico et al. 2009, Seabra et al. 2008). For example, Borraccino and associates (2009) investigated the influence of SES on the number of students (11, 13, and 15 years) living in 32 European countries according to compliance of PA guidelines provided by the World Health Organization. In three-quarter of all countries (i.e., 24), the relative risk of not complying PA guidelines (i.e., 60 minutes of moderate to vigorous PA for at least five days a week) was significantly higher in students of low and middle as compared to high SES. Furthermore, reports by Federico et al. (2009) and Seabra et al. (2011) addressed the association between SES and level of PA among students from Italy (6-17 years) and Portugal (10-18 years), respectively. Both research groups found that students in the high compared to those in the low SES-group more often engaged in moderate and vigorous levels of PA. It has to be mentioned that a high level of physical fitness is negatively associated with various cardiovascular and fall/injury risk factors in children. In fact, Artero et al. (2011) reported that cardiorespiratory (i.e., 20-m SRT) and muscular fitness (i.e., SLJ) were independently associated with clustered metabolic risk (e.g., waist circumference [WC], systolic blood pressure [BP], cholesterol, insulin

resistance [IR]) in students aged 12-17 years. More precisely, 8- to 11-year olds that achieved the upper quartile (i.e., quartile 4) in muscular fitness score as computed by performances in tests of SLJ and hand grip strength had a significantly better cardiometabolic risk profile (e.g., WC, body fat, pubertal status, BP, cholesterol, IR) as compared to children belonging to the middle (i.e., quartile 2 and 3) and lower fitness quartiles (Diez-Fernandez et al. 2015). At least, de Moraes et al. (2013) revealed a positive association between performance in SLJ-test and quantitative and qualitative measures of bone health (i.e., amplitude -dependent speed of sound, ultra sound bone profile index) in a sample of 11- to 16-year olds.

Regarding the health benefits that arises from sufficient physical fitness it has to be discussed to what extent the inferior performance in children of middle and/or low SES compared to high SES-group as well as less percentage of high fit children in middle and low SES-group might indicate a more insufficient physical fitness profile (as compared to high SES-group). In the latter case (high fitness level) it is vital to remember that importance should not be attached to the absolute prevalence of high fitness level, since the definition of high physical fitness level based on relative sample-specific cut-points. Consequently, prevalence of high fitness ought to be used only for relative comparisons between groups of SES. For this purpose performances in the SLJ-test and the 6-min run test in children among SES-groups were compared to age- and sex-specific reference data derived from the representative German 'MoMo-study' (i.e., age groups: 7, 8, 9, and 10 years). By means of quintile-classification performance was expressed as: 'far below average' (i.e.,  $x \leq$  percentile [P] 20), 'below average' (i.e.,  $P20 < x \leq P40$ ), 'average' (i.e.,  $P40 < x \leq P60$ ), 'above average' (i.e.,  $P60 < x \leq P80$ ), and 'far above average' (i.e.,  $P80 < x$ ). The comparison for the 6-min run test revealed that independent of age group and sex, children of middle and low SES achieved at least the 'average' performance category. There were no differences to the classification of performance in high SES-group. Of note, independent of SES-group and sex, performances in seven- and eight-year-olds refers to classification of 'far above average' (7 years) and 'above average' (8 years). The comparison for the SLJ-test likewise showed no differences in classification of performance between SES-groups. It has to be mentioned that according to the German reference data performances in the SLJ-test in nine- and ten-year-olds refers to classification of 'below average', whereas younger classmates' performance characterized 'above average' (7 years) and 'average' (8 years) performance. In summary, even though children attending schools in communities of low and middle SES showed inferior performances in proxies of CRF and muscular power as compared to high SES-group it can be suggest that these cohorts are not more faced with an insufficient physical fitness profile and potentially associated unfavorable health status. Of note, with regard to the below average performance classification of nine- to ten-year-olds of the present sample in the SLJ-test comparisons with further recently published percentile norm values from seven to ten year old boys and girls from Spain (Castro-Piñero et al. 2009) and Portugal (Roriz De Oliveira et al. 2014) outlined that performances of nine and ten year olds of the present sample refers at least to the 50. percentile - independent of SES-group.



### *Limitations*

There are potential limitations of this study that warrant discussion. One, limitation is the indirect characterization of SES. With the aim of investigating the entire population of third graders in one German federal state (i.e., about 18,000 subjects) for their physical fitness according to SES and associated ministerial provisions one had to decide for an indirect measurement of children's socioeconomic factors. However, the investigation of differences in youth's health and behavior (i.e., obesity, diet, physical fitness and physical activity) in terms of SES by means of area-/community related SES-data is not a novelty and was even successfully applied in previous studies (Bailey et al. 2012, Fairclough et al. 2009, Humbert et al. 2006, Janssen et al. 2006). For example, research group of Janssen (Janssen et al., 2006) applied both individual- and area-level measures of SES to investigate the impact of SES on amongst others obesity. Area-level-based SES defined the geographic area (5-km radius) surrounding each of the participating schools and included three variables which are similar to these used within the study of the present thesis (i.e., unemployment rate, percentage of adult residents with less than a high school education, and average employment income from head of household). All area-level SES variables were inversely associated with obesity. This relation-pattern was observed to the same extent by analysis for applied individual-level SES variables (i.e., material and perceived family wealth) which is also an argument for sensitivity of area-/community-related SES-variables.

Regarding statistical analysis, it has to be mentioned that that significant p-values in analyses of mean differences are a common consequence of big sample sizes (Bortz 2005, Field 2013). Therefore, effect size as relative measure of effect, must be quoted too. Indeed, analysis revealed just small effect sizes (Cohen's  $[d] = 0.00-0.26$ ) for significant performance differences in terms of SES (boys:  $0.06 \leq d \leq 0.26$ ; girls:  $0.06 \leq d \leq 0.21$ ) (i.e., SLJ and 6-min run). This suggests a weak practical meaning of SES on children's physical fitness. An explanation for small effect sizes might be the multifactorial etiology of individual's fitness, especially in children. In fact, applied statistical methods only considered for organized sports participation (i.e., participation in sports clubs and/or extra-curricular physical education classes) and chronological age. As cited above, it is well documented that a vast amount of other determinants of child's physical fitness exists like body composition, general physical activity, diet, or parental physical fitness and activity habits that are associated with child's SES. However, with respect to the educational frame in which the study of the present thesis was placed (i.e., evaluation of physical fitness as mandatory part of physical education classes) and associated ministerial provisions it was not possible to include measures like body size. Furthermore, small effect sizes might be caused by relatively high standard deviations of means in the present sample. The heterogeneity of physical fitness performances among pupils of the same school grade is common placed and inter alia caused by high variations of chronological age. A recently published study by Tomatis et al. (2014) picked up this issue in a sample of first graders from Swiss with a wide age range. However, due to the lack of comparable studies (i.e., representative school-based physical fitness evaluations at one grade) that reported effect sizes, this assumption cannot be confirmed. In addition, small effects of

SES-related in youth were also reported in previous studies, especially for the SLJ-test (Jiménez Pavón, Ortega, Ruiz, Chillón, et al. 2010, Jiménez Pavón, Ortega, Ruiz, España Romero et al. 2010). Lastly, the cross-sectional nature of the study represents a further limitation as it does not enable to establish causality between SES and physical fitness.

## 8. Conclusion

In a first conclusive step, the generated percentile values provide an objective opportunity to estimate children's physical fitness within the frame of physical education (e.g., age- and sex-specific grading of motor performance) and further to detect children with specific fitness characteristics (low fit or high fit) that may be indicative for the necessity of preventive health promotion or long term athlete development. In this regard, physical fitness testing should be considered as an instrument to encourage increase physical activity and exercise and not be an end in itself.

Second, it is essential to consider variables of different domains (e.g., environment and behavior) in order to improve knowledge of potential factors which influence physical fitness during childhood. In this regard, the present thesis provide a first input to clarify the causality of living area and sports club participation on physical fitness development in school-aged children. Living in urban areas as well as a regular participation in sports clubs positively affected children's physical fitness development (i.e., muscular power and CRF). Herein, sports club participation seems to be a key factor within the relationship between living area and physical fitness. At least, the findings of the present thesis imply that attending schools in communities with high SES refers to better performance in specific physical fitness test items (i.e., CRF, muscular power) in third graders. Extra-curricular physical education classes may represent an important equalizing factor for physical activity opportunities in children of different SES backgrounds. With regard of strong evidence of a positive relationship between physical fitness - in particular muscular fitness/ CRF - and health, more emphasis should be laid on establishing sports clubs and extra-curricular physical education classes as an easy and attractive means to promote fitness-, and hence health-enhancing daily physical activity for all children (i.e., public health approach).

At least, schools play an important role in identifying children with low/high fitness as well as in promoting positive fitness enhancing behaviours.

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**Authors' contribution**

The present thesis is designed as a cumulative dissertation. In this regard, three scientific articles have been prepared, submitted to peer-reviewed journals, and accepted for publication (study 2) or be still under review (study 1, study 3). According to the local doctoral degree regulations (§ 7 (4), sentence No. 2), significant contributions to the articles from the respective co-authors were acknowledged and finally confirmed by each co-author:

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Study	Design	Data selection	Data Analyses	Interpretation	Manuscript
Study 1	DW, <b>KG</b> , UG	DW, <b>KG</b> , UG	TM, <b>KG</b> , UG	<b>KG</b> , TM, UG, DW	TM, <b>KG</b> , UG
Study 2	DW, <b>KG</b> , MH, UG	DW, <b>KG</b> , MH, UG	TM, <b>KG</b> , UG	<b>KG</b> , TM, UG, MH, DW	TM, <b>KG</b> , UG
Study 3	DW, <b>KG</b> , MH, UG	DW, <b>KG</b> , MH, UG	TM, <b>KG</b> , UG	<b>KG</b> , TM, UG, MH, DW	TM, <b>KG</b> , UG

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