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Motor and Cognitive Performance in Kindergarten Children

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Abstract

Childhood compared to adolescence and adulthood is characterized by high neuroplasticity represented by accelerated cognitive maturation and rapid cognitive developmental trajectories. Natural growth, biological maturation and permanent interaction with the physical and social environment fosters motor and cognitive development in children. Of note, the promotion of physical activity, physical fitness, and motor skill learning at an early age is mandatory first, as these aspects are essential for a healthy development and an efficient functioning in everyday life across the life span and second, physical activity behaviors and lifestyle habits tend to track from childhood into adulthood.

The main objective of the present thesis was to optimize and deepen the knowledge of motor and cognitive performance in young children and to develop an effective and age-appropriate exercise program feasible for the implementation in kindergarten and preschool settings. A systematic review with meta-analysis was conducted to examine the effectiveness of fundamental movement skill and exercise interventions in healthy preschool-aged children. Further, the relation between measures of physical fitness (i.e., static balance, muscle strength, power, and coordination) and attention as one domain of cognitive performance in preschool-aged children was analyzed. Subsequently, effects of a strength-dominated kindergarten-based exercise program on physical fitness components (i.e., static balance, muscle strength, power, and coordination) and cognitive performance (i.e., attention) compared to a usual kindergarten curriculum was examined.

The systematic review included trials focusing on healthy young children in kindergarten or preschool settings that applied fundamental movement skill-enhancing intervention programs of at least 4 weeks and further reported standardized motor skill outcome measures for the intervention and the control group. Children aged 4-6 years from three kindergartens participated in the cross-sectional and the longitudinal study. Product-orientated measures were conducted for the assessment of muscle strength (i.e., handgrip strength), muscle power (i.e., standing long jump), balance (i.e., timed single-leg stand), coordination (hopping on right/left leg), and attentional span (i.e., “Konzentrations-Handlungsverfahren für Vorschulkinder” [concentration-action procedure for preschoolers]).

With regards to the scientific literature, exercise and fundamental movement skill interventions are an effective method to promote overall proficiency in motor skills (i.e., object control and locomotor skills) in preschool children particularly when conducted by external experts with a duration of 4 weeks to 5 months. Moreover, significant medium associations were found between the composite score of physical fitness and attention as well as between coordination separately and attention in children aged 4-6 years. A 10-weeks strength-dominated exercise program implemented in kindergarten and preschool settings by educated and trained kindergarten teachers revealed significant improvements for the standing long jump test and the Konzentrations-Handlungsverfahren of intervention children compared to children of the control group.

The findings of the present thesis imply that fundamental movement skill and exercise interventions improve motor skills (i.e., locomotor and object control skills). Nonetheless, more high-quality research is needed. Additionally, physical fitness, particularly high performance in complex fitness components (i.e., coordination measured with the hopping on one leg test), tend to predict attention in preschool age. Furthermore, an exercise program including strength-dominated exercises, fundamental movement skills and elements of gymnastics has a beneficial effect on jumping performance with a concomitant trend toward improvements in attentional capacity in healthy preschool children. Finally, it is recommended to start early with the integration of muscular fitness (i.e., muscle strength, muscle power, muscular endurance) next to coordination, agility, balance, and fundamental movement skill exercises into regular physical activity curriculums in kindergarten settings.

Zusammenfassung

Das Kindesalter ist im Vergleich zum Jugend- und Erwachsenenalter durch eine hohe Neuroplastizität, charakterisiert, welche durch beschleunigte Reifungsprozesse und rasche kognitive Entwicklungsverläufe gekennzeichnet ist. Natürliches Wachstum, biologische Reifung und die permanente Auseinandersetzung mit der physischen und sozialen Umwelt unterstützen und fördern die motorische und kognitive Entwicklung von Kindern. Bemerkenswert ist, dass bereits ab dem frühen Kindesalter die Förderung von körperlicher Aktivität, motorischen Fähigkeiten und Fertigkeiten unablässig ist, da sie zum einen wesentliche Faktoren für eine gesunde Entwicklung sowie eine effiziente alltägliche Funktionstüchtigkeit im Lebensverlauf darstellen und zum anderen das Aktivitätsverhalten und die Lebensgewohnheiten des Kindesalters tendenziell ins Erwachsenenalter übernommen werden.

Die Zielstellung der vorliegenden Arbeit war es, das Wissen über motorische und kognitive Leistungsfähigkeit im frühen Kindesalter zu vertiefen und effektive altersgerechte Bewegungsprogramme für die Umsetzung im Setting Kindertagesstätte zu entwickeln. Es wurde ein systematisches Review mit Metaanalyse erarbeitet, um die Effekte von Bewegungsprogrammen zur Verbesserung elementarer Bewegungsfertigkeiten bei gesunden Vorschulkindern zu untersuchen. Zudem wurden die Zusammenhänge zwischen motorischen Fähigkeiten (z.B. statisches Gleichgewicht, Maximalkraft, Schnellkraft und Koordination) und der Konzentration, als ein Bereich der kognitiven Leistungsfähigkeit, im Kindesalter analysiert. Anschließend wurde die Wirksamkeit eines kraft-orientierten Bewegungsprogramms gegenüber einem gewöhnlichen Kindergartencurriculums auf motorische Fähigkeiten, wie statisches Gleichgewicht, Maximalkraft, Schnellkraft und Koordination sowie auf kognitive Leistungsfähigkeit, wie die Konzentration, überprüft.

Das systematische Review beinhaltete Studien mit gesunden jungen Kindern im Setting Kindertagesstätte, welche Bewegungsprogramme von mindestens 4 Wochen zur Verbesserung der elementaren Bewegungsfertigkeiten durchführten und Ergebnisse der Interventions- sowie Kontrollgruppen mithilfe standardisierter motorischer Tests berichteten. In der Querschnitts- und Längsschnittstudie nahmen Kinder im Alter von 4-6 Jahren aus drei Kindertagesstätten teil. Ergebnisorientierte motorische Messungen wurden durchgeführt, um die Maximalkraft (Handkraft), die Schnellkraft (Standweitsprung), das Gleichgewicht (Einbeinstand), die Koordination (einbeiniges Hüpfen rechts/links) und die Konzentrationsfähigkeit (Konzentrations-Handlungsverfahren für Vorschulkinder (KHV-VK)) zu erheben.

Mit Bezug zur wissenschaftlichen Literatur stellen Bewegungsprogramme eine effektive Möglichkeit dar, motorische Fertigkeiten (lokomotorische sowie objektbezogene Fertigkeiten) bei Vorschulkindern zu fördern, vor allem, wenn sie von externen Experten durchgeführt werden und eine Dauer von 4 Wochen bis 5 Monaten haben. Darüber hinaus konnten signifikante Zusammenhänge zwischen motorischen Fähigkeiten und der Konzentration sowie insbesondere zwischen der Koordination allein und der Konzentration bei Kindern im Alter von 4-6 Jahren gefunden werden. Ein 10-wöchiges kraft-orientiertes Bewegungsprogramm, welches durch geschultes und qualifiziertes Kindergartenpersonal in Kindertagesstätten durchgeführt wurde, führte zudem zu signifikanten Verbesserungen im Standweitsprung und im KHV-VK bei Kindern der Interventionsgruppe im Vergleich zu Kontrollgruppe.

Die Ergebnisse der vorliegenden Arbeit zeigen, dass Bewegungsprogramme motorische Fertigkeiten, wie lokomotorische und objektbezogenen Fertigkeiten, verbessern. Dennoch gibt es Bedarf an weiterführenden, methodisch gut designten und qualitativ hochwertigen Interventionsstudien. Motorische Fähigkeiten, besonders gut ausgebildete komplexe Fähigkeiten wie die Koordination (gemessen mit dem einbeinigen Hüpfen), scheinen die Konzentrationsfähigkeit im Vorschulalter zu beeinflussen. Zudem verbessert ein Trainingsprogramm mit kraft-orientierte Übungen, elementare Bewegungsfertigkeiten und turnerischen Elementen die Sprungleistung und scheint gleichzeitig einen Einfluss auf die Konzentrationsfähigkeit bei gesunden Vorschulkindern zu haben. Letztendlich empfiehlt es sich, bereits in jungen Jahren Kraftfähigkeiten, wie Maximal- und Schnellkraft und Kraftausdauer neben Koordination, Agilität, Gleichgewicht und elementaren Bewegungsfertigkeiten zu schulen und diese in regelmäßige Bewegungsstunden im Setting Kindertagesstätte zu integrieren.

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Figure 1: Overview of published studies and their relation to another including a summary of the research focus. IF, impact factor 16

Abbreviations

rANCOVA	Repeated-measures analysis of covariance
BMI	Body mass index
CDC	Centers for Disease Control and Prevention
d	Effect size according to Cohen
EPHPP	Effective Public Health Practice Project—Quality Assessment Tool for Quantitative Studies
F and F^2	Effect size according to Cohen
GRADE	Grading of Recommendations Assessment, Development, and Evaluation System
IF	Impact Factor
KHV-VK	Konzentrations-Handlungsverfahren für Vorschulkinder
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
r	Pearson product-moment correlation coefficient
SD	Standard deviation
SMD	Standardized mean difference
TGMD-2	Test of Gross Motor Development 2^{nd} Edition
vs.	Versus
WHO	World Health Organization

1 General introduction

Early childhood represents a critical developmental period which is characterized by dynamic changes in motor and cognitive development due to growth and biological maturation. Essentially, this time of life lays the foundation for the establishment of healthy or unhealthy behaviors later in life. For purpose of this thesis, the terms early childhood, kindergarten, and preschool age are used interchangeably and refer to ages 3-6 years, before school entry.

The acquisition and mastery of fundamental movement skills predominantly evolve during the preschool age (Stodden et al., 2008). Moreover, the proficiency of these basic motor skills, including confidence and perceived motor competence to perform these skills, build the foundation for more complex and sport-specific skills (Robinson et al., 2015; Stodden et al., 2008). As such, adequate competencies in fundamental movement skills are considered critical to achieving and maintaining a sufficient level of physical activity (Larsen et al., 2015) and fitness (Cattuzzo et al., 2016), and vice versa (Faigenbaum & Bruno, 2017; Larsen et al., 2015). Children need a certain amount of muscular fitness (i.e., muscle strength, muscle power, local muscular endurance) to adequately jump, hop, throw, kick, run, move with energy and vigor, and engage in plays and games with peers (Faigenbaum & Bruno, 2017; Myer et al., 2011).

To achieve the full potential and benefits that continuous physical activity has on a child's emotional, social, and cognitive well-being and on their cardiorespiratory and musculoskeletal fitness, the Center for Disease Control and Prevention (CDC) and the World Health Organization (WHO) recommend children aged 3-5 years be physically active on a daily basis for at least 60 and up to 180 minutes (Bull et al., 2020; CDC, 2020).

In fact, motor skill learning and an adequate level of physical fitness are not only achieved through natural development, maturation, or by being active for at least 60 minutes a day, but also by continuous interaction with a stimulating and supportive environment that includes adequate exercise stimuli and professional instruction as well as feedback (Gabbard, 2009). This aspect must be addressed to parents or legal guardians, educators, and childcare and kindergarten teachers: Firstly, to keep them informed on how children learn and consolidate motor skills as well as physical fitness, and, secondly, to emphasize the importance of a regular interactive, age-appropriate physical activity and exercise program which has to be supervised to some extent. More precisely, childhood, compared to adolescence and adulthood, is characterized by high neuroplasticity represented by accelerated cognitive maturation and rapid cognitive developmental trajectories (Anderson et al., 2001), both of which not only support cognitive performance, but also have an important influence on motor skill learning and development (Haapala, 2013). Moreover, mutual interactions between motor and cognitive performance take place while being physically active (Diamond, 2000; Leonard, 2016).

Subsequently, children with reduced levels of physical activity, below current recommendations of at least 60 minutes daily moderate-to-vigorous physical activity, are somewhat likely to suffer from exercise deficit disorder (Faigenbaum & Myer, 2012; Myer, Faigenbaum et al., 2013). These deficits in experiencing a variety of physical activities on a regular basis early in life will lead to low motor skill proficiency and low levels of perceived motor competence, however, both of which require the child to be regularly physically active (Logan et al., 2012; Seefeldt, 1980). Nevertheless, evidence-based research reports that declines in daily physical activity already start with school entry at approximately 6-7 years and then develop progressively (Farooq et al., 2018). Taking this into account, it is crucial to start early in promoting motor skill learning and to foster physical fitness development by providing children with prerequisites to engage in recommended physical activity. As physical activity behaviors and lifestyle habits established during childhood tend to track into adulthood (Kristensen et al., 2008; Telama et al., 2014), and to prepare youth for a life-long engagement in physical activity, it is important to intervene and promote physical activity, physical fitness, and motor skill learning at an early age when habits are still under formation (Hardy et al., 2012; Jaakkola et al., 2019; Stodden et al., 2013).

Faigenbaum and Bruno (2017) postulated that early childhood seems to be an opportune time to intervene with age-appropriate and joyfully exercise interventions. Those interventions should enhance especially physical fitness, particularly muscle strength coordination, agility, balance, and fundamental movement skills, rather than only increase the quantitative (i.e., recommendations - minutes spent in daily physical activity) component of physical activity (Faigenbaum & Bruno, 2017; Myer et al., 2015).

From a public health perspective, kindergartens, preschools, and childcare centers may be an ideal setting to implement and manifest physical activity, fitness, and exercise intervention programs as a large number of children can be reached on a regular basis and at an early age (Robinson et al., 2015).

Thus, the main objective of this thesis is to evaluate kindergarten, preschool, or childcare-based exercise interventions in children aged 3-6, and to examine the possible association between motor and cognitive performance. Both of which are considered important factors for a healthy upbringing, to further develop a feasible, age-appropriate exercise program to effect motor and cognitive development in preschool children. The present cumulative thesis complies a systematic review, a cross-sectional and a longitudinal study. All studies were recently published in peer-reviewed journals

(Wick et al., 2017; Wick et al., 2021, 2022). The systematic review and the longitudinal study analyze the effects of motor skill and physical fitness intervention programs on fundamental movement skills and measures of physical fitness (i.e., static balance, muscle strength, power, and coordination), and cognitive performance (i.e., attention). Furthermore, the cross-sectional study examines associations between physical fitness (i.e., static balance, muscle strength, power, and coordination) and attention.

The following chapter (2) provides a literature overview on motor and cognitive performance in early childhood, including a summary of definitions and constructs. Current studies focusing on motor skill and physical fitness interventions are reviewed as well as tools for motor and cognitive assessments. The dynamic relationship of motor performance including fundamental movement skills and physical fitness with physical activity, cognitive performance, and health are discussed.

2 Literature review

2.1 Motor performance

Scientific literature uses multiple terms analogous and/or interchangeable to motor performance, i.e., motor proficiency, motor ability, motor coordination, fundamental movement or motor skill, motor competence, movement skill competence. Although, most definitions and concepts agree that (movement or motor) skills are included, Logan et al. (2018) criticized the interchangeable terminology, arguing it is not precise enough does not refer to the same constructs. In this thesis motor performance is understood as the level of motor skill proficiency. Furthermore, motor performance is defined as the ability to execute a variety of gross and fine motor skills including whole-body movements that involve large muscles in the torso, legs and arms as well as manual dexterity (Haga, 2008). Finally, motor performance significantly impacts physical fitness and also relies on the optimal exploitation of these components during the execution of motor skills (Ortega et al., 2008). As motor performance has a developmental nature, it is characterized as a (learning) process where continuous changes in motor behavior and performance occur over time from childhood to adulthood (Gallahue et al., 2012; Malina, 2014). Motor development depends to a large extent on current neuromuscular maturation processes in interaction with biological growth processes (i.e., body height, body mass) (Malina, 2014). Moreover, the development of motor performance is driven by an interaction between the individual, the (motor) task, and the social and physical environment (i.e., home, day care, kindergarten, preschool, peers) (Gallahue et al., 2012). External stimuli, sufficient and professional feedback, and motivation are needed to foster the acquisition of movement patterns and motor performance (Gabbard, 2009; van Sluijs & Kriemler, 2016).

During early childhood, motor performance can be reflected by the ability to adequately perform fundamental movement skills like jumping, running, hopping, or throwing (Stodden et al., 2008) with the optimal use of muscular strength, coordination flexibility, speed, and balance (Faigenbaum & Bruno, 2017).

2.1.1 Fundamental movement skills

Everyday activities as well as more specialized and complex activities used in sports and games require a certain level and a variety of motor skills. Thereby, fundamental movement skills are considered the basic abilities and skills that children start to learn during early childhood (Stodden et al., 2008). In essence, these basic movement patterns, involving a series of various body parts and muscles, are essential prerequisite skills for developing more refined, complicated, and sport-specific skills used in leisure time pursuits and organized sports later in life (Gallahue et al., 2012; Haywood & Getchell, 2003; Lloyd et al., 2015). Fundamental movement skills are categorized into locomotor skills, which are referred to movements of the body through space like running, jumping, or sliding, and object control skills that enable children to manipulate and project objects such as throwing, catching, or kicking (Cools et al., 2009; Haywood & Getchell, 2003).

As proficiency in fundamental movement skills is an important contributor to a child's physical fitness level (Cattuzzo et al., 2016), and vice versa (see 2.1.2), it will form and maintain future physical activity behavior (Gallahue et al., 2012; Logan et al., 2015; Seefeldt, 1980), meaning early childhood is a sensitive time where a sufficient diverse motor repertoire evolves. As most preschool children are naturally curious and have an urge to move, and love to play, fundamental movement skills can be learned and practiced easily (Cools et al., 2009).

Children with deficits in fundamental movement skills at preschool age are less confident in performing these skills (Seefeldt, 1980; Stodden et al., 2008). Further, they are experiencing difficulties (so-called "proficiency barrier" (Seefeldt, 1980)) when attempting more complex and sport-specific skills in middle childhood to adolescence starting primary and secondary school. As a consequence, those children are more likely to have a less active lifestyle so as to avoid movement difficulties (Wrotniak et al., 2006), to spend less time physically active, and to be less willing and able to engage in various leisure time, or organized or competitive sports (Lopes et al., 2020). Indeed, the motivation to take part in different kinds of physical activities is significantly related to the level of motor performance (Larsen et al., 2015).

2.1.1.1 Studies on fundamental movement skills in preschool children

A recent study from Lopes et al. (2020) demonstrates that studies on the prevalence in fundamental movement skills, especially in preschool children, are scarce. For school-aged children, Hardy et al. (2013) compared data from three surveys (1997, 2004, 2010) assessing fundamental movement skills (sprint run, vertical jump, catch, kick, and overarm throw) in children aged 9–15 years, finding that in general, motor skill competency was low with a prevalence rarely above 50%. Especially among 4th grade children, there was a high prevalence of low levels of fundamental movement skills, which underlies the need to start promoting motor skill learning during the preschool and early school years (Hardy et al., 2012). Findings from Roth et al. (2010) revealed inconsistent findings in children aged 3-6 years, showing secular declines only in some motor skills (i.e., balancing backwards and target throwing), while children performed equally well over time (i.e., obstacle course) or even better in other skills (i.e., standing long jump).

In the past, several reviews from the large amount of single research studies on the topic, have elucidated the effects of fundamental movement skill interventions on fundamental movement skills in children as those strategies may have positive effects on children's motor skill development. Thereby, most reviews have focused on healthy school rather than preschool children (Lai et al., 2014; Morgan et al., 2013), on children with motor coordination disorders or delays (Pless et al., 2000; Smits-Engelsman et al., 2013), or reviews have examined the effects of physical activity on fundamental movement skills (Ling et al., 2015; Mehtälä et al., 2014). However, Logan et al. (2012) and Riethmüller et al. (2009) focused on healthy preschool children and the effectiveness of interventions to improve fundamental movement skills, although, both reviews lack topicality and are methodologically limited. Riethmüller et al. (2009) demonstrated that 60 % of the 17 included studies showed statistically significant intervention effects but, however, those effects have not further been analyzed by a meta-analysis due to low methodological quality and large heterogeneity of the included studies. Findings of Logan et al. (2012) showed small effect sizes, ranging from 0.39 to 0.45, for overall fundamental movement skills, object control, or locomotor skills for fundamental movement skill interventions. However, these meta-analytical results were calculated based solely on the pre-post measurements of the intervention groups undergoing the importance of a control group to accurate establish a cause-and-effect relationship of fundamental movement skill interventions (Liberati et al., 2009).

2.1.1.2 Measurements of fundamental movement skills

To adequately evaluate and monitor a child's competence in performing fundamental movement skills throughout childhood, the validity and reliability of the respective skills' measurement is crucial (Logan et al., 2017). The assessment tools for measuring fundamental movement skills in childhood are diverse, numerous, and can be divided either into process- or product-orientated measurements (Hulteen et al., 2020). While process-orientated assessment tools measure the quality of movement skills during execution (e.g., how a skill is performed), product-orientated assessment tools focus on quantitative aspects (e.g., time, distance, or number of successful attempts) which measure the outcome of a skill execution. No matter what assessment tool is used (process- or product-orientated), the examination of motor skills provides the opportunity to detect, as early as possible, children who are at risk of motor delays, enabling support and the supervision of optimal motor skill learning, as well as the prevention of developmental disadvantages in later childhood and adolescence, stemming from an early age onwards (Gallahue et al., 2012). Thereby, with process-orientated assessment tools a child's level of movement techniques with predetermined criteria (criterion-referenced) can be evaluated (Logan et al., 2017; Lopes et al., 2020). Possible weaknesses of specific movement components (i.e., key points) of a motor skill can be consequently practiced and improved after detection. However, process-orientated assessment tools require a large amount of time for the execution. At least two assessors, who are trained to carry out these measurements, score predetermined criteria - the presence of specific features (i.e., key points) - of a movement skill. Product-orientated measurements deliver outcome data of a skill execution which can be compared to data of a normative group (a sample that is representative of the target group regarding specific aspects, e.g., age, sex, socioeconomic status – norm-referenced) (Logan et al., 2017; Lopes et al., 2020). In contrast to process-orientated assessments, quantitative measurements are easier to administer as the scoring guidelines indicate clear-cut points of movement skill outcomes defining a failed or successful attempt.

Most importantly, the choice for a specific assessment tool should be determined by the purpose of the information needed and by the research question of a study, the target group (i.e., age, setting,) (Logan et al., 2011; Lopes et al., 2020), and the assessor (i.e., scientists, physiotherapists, kindergarten teachers). From a practical point of view, measuring tools have to be easy and intuitively to use, to analyze and interpret, as well as feasible, particularly when looking at time, effort, costs, and level of expertise required, to apply in a kindergarten or preschool setting (Cools et al., 2009; Logan et al., 2017; Lopes et al., 2020).

2.1.2 Physical fitness

Caspersen et al. (1985) defined physical fitness as a multi-component construct of genetically determined, but also trainable, attributes that relate to the ability to carry out daily tasks with alertness, vigor, and sufficient energy. Physical activity and exercises are some of the main determinants which influence physical fitness. In addition, physical fitness components can be classified into health-related skills (i.e., cardiorespiratory endurance, muscle strength, muscular endurance, flexibility, and body composition), which are usually associated with disease prevention, and health promotion and skill-related fitness components (i.e., agility, balance, coordination, speed, power, reaction time), which pertain more to athletic ability and performance (Caspersen et al., 1985). The development of physical fitness components is partly related to age and influenced by biological growth and maturation (Malina, 2014), meaning that with increasing age, physical fitness levels increase independent of physical activity behavior. Nevertheless, to adequately improve physical fitness in childhood and adolescence, opportunities to be regularly physically active and competencies in fundamental movement skills are needed.

From a health-related perspective, physical fitness is considered to be an important biomarker of health (Ortega et al., 2008) as high levels of fitness during childhood and adolescence may positively influence adult health (Moliner-Urdiales et al., 2010). Moreover, higher levels of physical fitness enable children to participate in a variety of activities, games and sports where they spend more time physically active (Faigenbaum et al., 2016). This active behavior established at an early age tends to track into adulthood (Telama et al., 2014) and will have a positive impact on numerous health benefits, whereby the more time spent doing physical activity, the greater the health benefit (Janssen & Leblanc, 2010; Malina, 2014; Smith et al., 2014). Besides the health-related perspective, physical fitness is an essential component of athletic performance, supporting the acquisition of fundamental, complex, and sport-specific motor skills, thereby enhancing motor performance and reducing the risk of sustaining sports-related injuries (Faigenbaum et al., 2016; Myer et al., 2015).

General health-oriented recommendations for preschool children focus on aerobic fitness (i.e., cardiorespiratory endurance) by recommending at least 60 and up to 180 minutes of physical activity per day (Bull et al., 2020; CDC, 2020), overlooking the importance of muscle strength and motor skill learning for optimal motor development at an early age (Faigenbaum & Bruno, 2017; Myer et al., 2015). Thereby, motor-skill enriched and intermittent activities which concentrate on different parameters of physical fitness, such as core strength and stability, coordination and agility, balance, muscular fitness (i.e., muscle strength, muscle power, muscular endurance), and fundamental movement skills, will produce beneficial effects on many health aspects, such as improved weight control, reduced risk of cardiovascular disease and type 2 diabetes, improved cognitive performance, and strengthened bones and muscles (Bull et al., 2020; CDC, 2020; Faigenbaum & Bruno, 2017). Faigenbaum and Bruno (2017) indicated that strength fitness (i.e., muscle strength, power, and muscular endurance) is an essential prerequisite for other physical fitness components and fundamental movement skills. More precisely, if children do not develop a sufficient level of muscle strength in concert with motor skill competencies during early childhood, they might be less proficient in jumping, running, throwing, or kicking, both in playground and later in life. Thus, Myer et al. (2013) introduced the term "exercise-deficit disorder" if children do not adhere to physical activity guidelines of at least 60 minutes per day and as a consequence may suffer from low motor skill proficiency, low perceived motor competence, increase time spend sedentary and increased risk of adverse health effects (Faigenbaum et al., 2016; Robinson et al., 2015; Schwarzfischer et al., 2019).

2.1.2.1 Studies on physical fitness in preschool children

As better physical fitness is associated with improved current and future health (Janssen & Leblanc, 2010; Ortega et al., 2008; Smith et al., 2014), it is alarming, that declining trends in physical fitness parameters have been observed, underlying a change in physical activity behavior of children and youth over the past decades (see Myer et al. (2013) “exercise deficit disorder” or Faigenbaum and Bruno (2017) “pediatric dynapenia”). Various systematic reviews worldwide have reported low levels of physical fitness and negative secular trends, particularly in school-aged children and adolescents, for cardiorespiratory endurance (especially between the years 1981 and 2000) (Tomkinson et al., 2019) and muscle strength and power (Fühner et al., 2021; Masanovic et al., 2020). A review by Bös et al. (2008) found that the decline in physical fitness was lower for children than for adolescents indicating that the promotion of physical fitness might be more effective in the long term if it is started at an early age as a prevention strategy, particularly with regard to the aspect that physical fitness and physical activity tend to track from childhood into adolescence and adulthood (Kristensen et al., 2008; Malina, 2014; Telama et al., 2014). Evidence from intervention studies promoting structured physical activity, physical fitness, aerobic games, and fundamental motor skills in preschool children seem to show such interventions are effective in increasing physical fitness (Latorre-Román et al., 2018; Niederer et al., 2011; Popović et al., 2020; Roth et al., 2015). Moreover, Lloyd and Oliver (2012) underlined, in their “youth physical developmental model”, the importance of promoting motor skills and physical fitness, particularly muscle strength, at all developmental stages, including early childhood.

2.1.2.2 Measurements of physical fitness

As physical fitness is a multi-component and theoretical construct (Caspersen et al., 1985), it cannot be measured directly. More specifically, whenever performing fundamental movement skills, varying degrees of physical fitness components (i.e., cardiorespiratory fitness, muscle endurance, muscle strength, muscle power, speed, flexibility, agility, balance, coordination, reaction time) are required (Gallahue et al., 2012) and will be part of and influence the skill execution. Upon these basic skills, product-orientated assessment tools (see 2.1.1.2) are used to indirectly measure physical fitness components on a quantitative basis. This might be challenging in early childhood as fundamental movement skills have to be developed to some extent to accurately measure physical fitness (Ortega et al., 2015). In sum, single measures of components of physical fitness contribute further to the construct of an individual’s physical fitness level regarding standardized data (see 2.1.1.2).

It can be argued that measuring physical fitness is different from measuring fundamental movement skills because both are distinct constructs and provide variable and precise but differential information (Logan et al., 2017; Palmer et al., 2021). Thus, Logan et al. (2017) point out this is an essential aspect of the diverse approach, namely that increases in qualitative assessment values are possible without an immediate and concurrent quantitative performance improvement. However, both fundamental movement skills and physical fitness are closely related (see 2.1.1 and 2.1.2) and constitute to overall motor performance. Nevertheless, it is crucial to focus on the purpose of assessment, particularly on what information (product- or process-orientated data) is needed and to whom it may concern (Logan et al., 2017) when choosing an adequate assessment tool.

2.2 Cognitive performance

Cognitive performance, as an umbrella term, denotes a whole set of mental actions or processes of acquiring knowledge and understanding through thought, experiences, and learning (i.e., acquisition, processing, storage, and use of information) (Gazzaniga et al., 2019).

Cognitive performance is a process which occurs due to biological maturation, growth, and the permanent interaction with the physical and social environment, and is next to motor performance and physical activity essential for a healthy development and an efficient functioning in everyday life across the life span (Anderson et al., 2001). More precisely, children develop and improve cognitive skills by being curious and actively examining and discovering their surroundings, as illustrated in Piaget's (1952) theory of cognitive development. Thus, the ability to move is a fundamental aspect of human life and, especially during childhood, a natural habit which constitutes an essential prerequisite of motor and cognitive development. Gogtay et al. (2004) postulate that rapid brain maturation occurs during early childhood continuing and decelerating until adolescence, with equally protracted developmental timetables for motor and cognitive development (Diamond, 2000). Those developmental windows offer optimal time points for positive intervention and the facilitation of development through enriched environmental conditions, adequate exercise stimuli, and professional instruction and feedback (Tomporowski et al., 2011) as brain structures and functions show particularly high neuroplasticity at early ages (Anderson et al., 2001). Thus, additional physical activity and exercise (e.g., care-based interventions, leisure time sports, or organized sports) could have the potential to positively influence brain development and academic achievements later in life (Álvarez-Bueno et al., 2017; Diamond & Ling, 2016).

Several research studies published in recent years have examined the relationship between components of motor performance and different aspects of cognitive performance in children

(Donnelly et al., 2016; Sibley & Etnier, 2003). For instance, Greier and Drenowatz (2019) reported weak correlations between physical fitness (i.e., balance (r = 0.21), coordination (r = 0.24)), and visuospatial working (measured with the "Human-Drawing-Test") in Austrian preschool children. Additionally, an earlier study by Voelcker-Rehage (2005) showed similar significant, although moderate, results for the association between physical fitness (i.e., reaction time (r = 0.41), coordination (r = 0.30)), fine motor skills (r = 0.34), and visual processing in 4- to 6-year-old children. Subsequently, van der Fels et al. (2015) reported that fundamental movement skills, particularly fine motor skills, and physical fitness (i.e., coordination, reaction time), had moderate to strong correlations with cognitive performance (i.e., memory, visual processing, executive functions, fluid intelligence) compared to gross motor and object control skills in 4 to 16-year-old children. Longitudinal studies examining the effects of physical activity and exercise programs on cognitive performance have mostly been done with school-aged children (Álvarez-Bueno et al., 2017; Fedewa & Ahn, 2011; Singh et al., 2019), and have produced rather inconclusive results (i.e., positive or no effects). Nevertheless, Fedewa and Ahn (2011) underlined the positive effects of physical activity and physical fitness, establishing that regular concurrent performance of aerobic exercise and perceptional motor training (3/week) over 36 weeks (academic school year) has the potential to improve not only cardiorespiratory endurance (i.e., aerobic fitness), but also cognitive (e.g., intellectual quotient) and academic performance (e.g., math and reading achievement) in school-aged children. Cognitive demanding exercises, such as coordination and complex exercises and games, may improve cognitive performance to a higher extent than plain aerobic exercises (Best, 2010; Schmidt et al., 2016; van den Berg et al., 2019; van der Fels et al., 2015).

The mechanisms underlying the effects of exercise and physical activity on cognitive performance are not a focus of the present study, but will be discussed in short, as they enhance the understanding of the importance of regular and long-lasting physical activity engagement across life. In the literature, acute and chronic effects of exercise and physical activity on cognitive performance can be differentiated, some of the acute effects comprise an increased blood flow (Querido & Sheel, 2007), increased arousal level, and increased activity level in certain areas of the brain. More importantly, chronic effects are diverse and include an increased concentration of growth factors which enhance the development of new blood vessels and neurons that cause changes in brain volume and increase the efficiency of neural networks (Fernandes et al., 2017; Ploughman, 2008).

2.2.1 Executive function

Executive function is a set of cognitive processes defined as higher-order cognitive skills which are necessary for complex, goal-directed, and social behavior (Anderson et al., 2001; Donnelly et al., 2016). The ability to focus, work with information in mind, filter distractions, and switch between either necessary or less important information is part of this cognitive process and essential for mental and physical health, as well as cognitive, social, and psychological development (Diamond, 2013; Gibb et al., 2021). Diamond (2013) and Miyake et al. (2000) mention three core executive functions (inhibitory control, working memory and cognitive flexibility) upon which higher-order executive functions are built, such as reasoning, problem-solving, and planning. During early and middle childhood, rapid maturation in executive functions takes place, significantly slowing down during late childhood and adolescence (Anderson et al., 2001). Different researchers have postulated that executive function is crucial for a child's adaptive behavior and have to be optimally developed to enable goal-directed and social behavior across life (Diamond, 2013; Robson et al., 2020). If children suffer from executive malfunctioning of an inability to focus and maintain attention, things such as extreme impulsivity, incapacity to inhibit established behaviors, difficulties transitioning to new activities or situations, and inflexibility of thinking may occur (Anderson et al., 2001; Anderson & Reidy, 2012).

The assessment of these complex skills in childhood, particularly early childhood, is rather challenging due to the multifactorial nature of measurements which involve various lower-order skills, such as pronounced language skills (i.e., expressive, receptive), visual perception, reading ability, and processing speed. Secondly, sustaining attention during cognitive assessments is difficult for younger children as they get tired quickly, and often fail to comply with non-appealing tasks (Anderson & Reidy, 2012). Anderson and Reidy (2012) further noted the lack of practice-oriented, norm-referenced assessment tools to measure executive function in preschool children.

Executive function is not a focus of the present thesis, but requires mention as there are several overlaps with the developmental constructs of attention (Mahone & Schneider, 2012) during preschool age.

2.2.2 Attention

Attention is one domain of cognitive performance, and is closely related to executive function (Mahone & Schneider, 2012). In order to facilitate goal-directed and adequate social behavior, attention networks play a decisive role in prioritizing sensory information by focusing on a relevant stimulus, as well as allocating attention among relevant inputs, thoughts, and actions while simultaneously ignoring irrelevant or distracting information to exert top-down (goal-driven) controlled processes (Gazzaniga et al., 2019; Kao et al., 2022). The ability to focus attention has been proposed to be a fundamental skill for learning and academic achievement (Hampton Wray et al., 2017; McClelland et al., 2013). Moreover, to prepare children for school entry (transition from kindergarten or preschool to primary school), the specific learning conditions at school (focus attention, listening, understanding, sitting still) and goal-directed and adequate social behavior, attentional capacity is a relevant factor. Perera (2005) demonstrated that attention has an impact on school readiness and positively influences the transition from kindergarten or preschool to primary school. In terms of academic performance, Alavi et al. (2019) and Pagani et al. (2012) found that attention in preschool age predicts academic achievement in the long term during the school years. Furthermore, as the development of attention networks and attentional control (i.e., interference control as part of the three core aspects of executive function) will continue from early childhood into adolescence (Rueda et al., 2004), serving as the foundation on which self-regulatory processes, emotional reactivity to the environment, and language evolve (Rothbart et al., 2011). The relationship between attention and motor performance was studied by Niederer et al. (2011) in a study featuring 245 preschool children. The authors reported weak cross-sectional correlation effect sizes for attention and measures of aerobic fitness ($r = 0.25$) and agility ($r = -0.11$). Moreover, they presented results from a longitudinal study which establish that future improvements of attentional capacity at school age is related to the former fitness level at preschool age. This again illustrates the close relationship between motor and cognitive development. Therefore, attention as one domain of cognitive performance and its relevant aspects within the educational context will be the main focus in the present thesis. In contrast to executive function assessments which have to measure a spectrum of skills, those of attention are less complex and are easy to apply (Mahone & Schneider, 2012).

3 Research objectives

In the previous literature review in chapter 2, motor and cognitive performance were introduced as complex constructs showing accelerated maturation and rapid developmental trajectories during childhood. Several studies have shown that both parameters are essential parts for healthy growth. However, over the last three decades, physical activity behavior of children has changed, and consequently a decline in daily physical activity, proficiency in motor skills, and physical fitness is noticeable, especially among school-aged children. Nonetheless, the preschool age seems to be a milestone in motor and cognitive development and possible preventive and supportive strategies for parents and practitioners (i.e., kindergarten and preschool teachers) need to be designed. Thus, gaps in the literature are described in the following chapter and thereon, three research objectives (study I-III) are established.

Regarding the effects of exercise interventions on fundamental movement skills in healthy preschool children, there is a lack of high quality research studies and systematic reviews including high quality meta-analyses irrespective of their potential as a valuable resource for the development of recommendations and guidelines, which may help physicians and practitioners in the decision making process (Panic et al., 2013; Young & Horton, 2005). Previous reviews in preschool children have shown positive effects on fundamental movement skills when implementing different physical activity or fundamental movement skill interventions, but these effects failed to provide solid evidence as the procedures (i.e., meta-analysis) and included studies were methodologically limited.

Research objective I:

The first objective was to systematically analyze the effects of fundamental movement skill interventions taking place in childcare or kindergarten settings on actual fundamental movement skills (object control and locomotor skills) focusing on healthy and typically developing children between 2-6 years of age. Thereby, two priori hypotheses were defined to explain expected heterogeneity (I^2 meta-analyses) among study results. It was hypothesized that longer intervention periods of 6-8 months were needed for a sustainable change in behavior and therefore, would be more effective than shorter intervention periods of less than 6 months. Furthermore, it was assumed that the methodological quality of trials would influence the results meaning that trials rated as “high quality” would be more effective than trials rated as “low quality”, using a slightly adapted version of the established “Effective Public Health Practice Project Quality Assessment Tool for Quantitative Studies” (EPHPP).

Additionally, all reported meta-analytical outcomes were categorized by the certainty in effect estimates using the GRADE approach.

When analyzing the relation between motor and cognitive performance, various research studies have focused on different measures of motor (i.e., fundamental movement skills and/or physical fitness) and varying domains of cognitive performance, particularly in school-aged children. Studies have demonstrated further inconclusive findings, ranging from positive (i.e., coordination and complex motor task) to no effects (i.e., gross motor skills, balance, cardiorespiratory endurance only) between motor and cognitive performance (i.e., attention, memory, visual processing). Nonetheless, more recent research studies regarding the associations between physical fitness, particularly muscle strength and power, and attention in preschool children are needed. In particular, strength fitness (i.e., muscle strength, power, and muscular endurance) is an essential prerequisite for other physical fitness components and fundamental movement skills, and attention is apparently a relevant factor to prepare children for school entry and specific conditions at school and influences academic performance later at school age.

***Research objective II**:*

The second objective was to assess the relationship between measures of physical fitness (i.e., static balance, muscle strength, power, and coordination) and attention as one domain of cognitive performance in healthy preschool children including the individual dimensions (qualitative – working accuracy, quantitative – working speed) of attention. Additionally, it was hypothesized that fitness components which need precise coordination during execution are more complex and require higher order cognitive skills, so are therefore related to attention in a stronger way than fitness components, which are more fundamental and less complex, without the need of a high skill level.

Subsequently, research studies can be expected to produce evidence that strength-dominated exercise programs are effective in increasing muscle strength in primary school-aged children and adolescents. In addition, those exercise programs facilitate cognitive performance. However, there is a gap in the literature regarding the optimal time to implement strength-dominated exercise programs and their effects on physical and cognitive performance at an early age. Whether such a program is even more effective in the long term if it is started at preschool age is discussed.

Research objective III:

The third objective was to investigate the effects of a kindergarten-based intervention program focusing on strength and gymnastic exercises in 4–6-year-old children. The hypothesis assumed that a strength-dominated exercise program is particularly effective if started early (i.e., kindergarten) and, therefore, would lay the foundation for optimal motor skill learning. It was hypothesized that a 10-weeks applied intervention program would be more effective compared to a regular kindergarten curriculum to increase physical fitness and cognitive development.

Figure 1 demonstrates the overview of the three published studies included in the present thesis, showing the relation of these studies to each other and their focus of research.

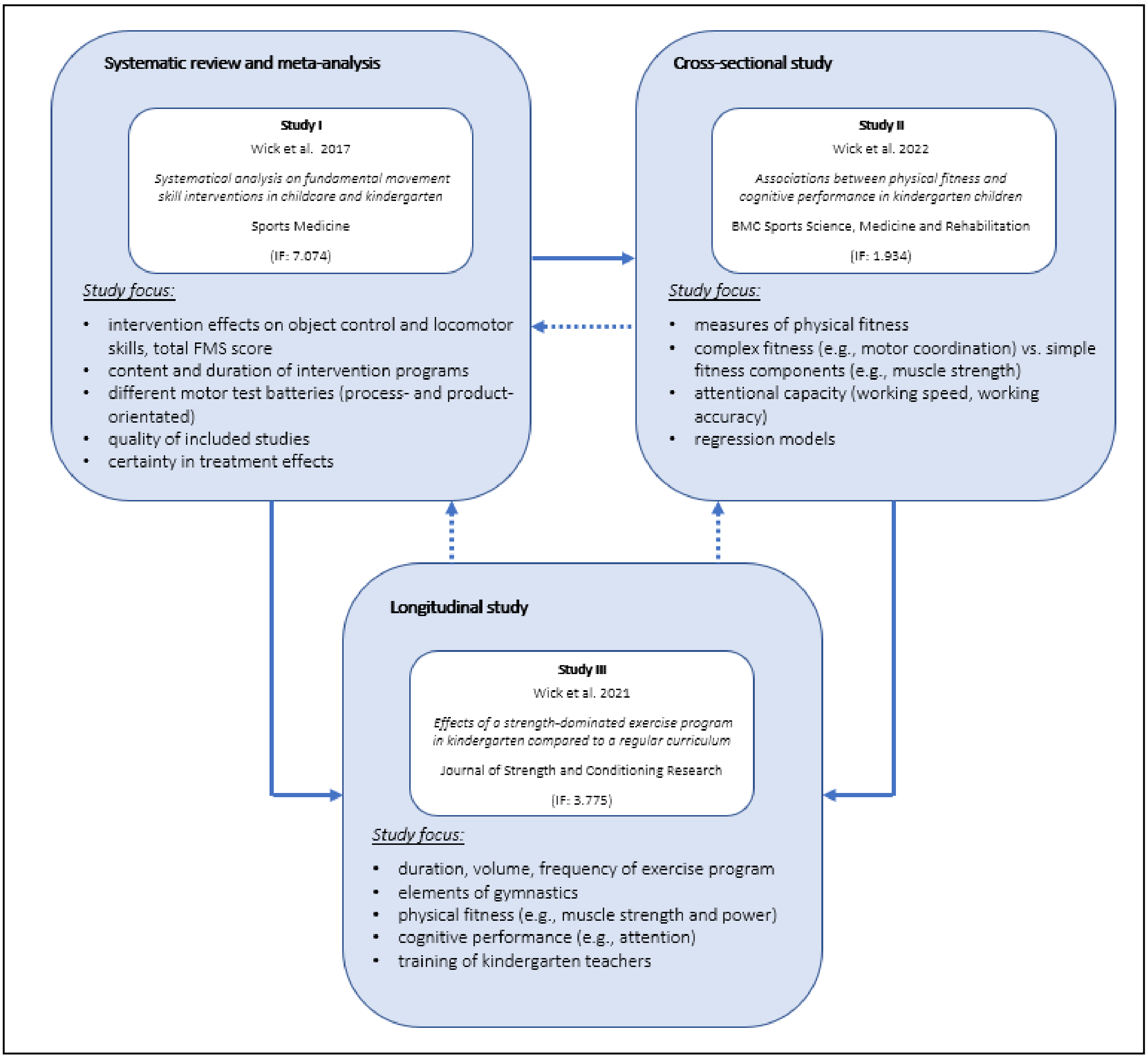

Figure 1 Overview of published studies and their relation to one another including a summary of the research focus. IF, impact factor

To address the above-mentioned research questions and objectives, this thesis generates a systematic review with meta-analysis on fundamental movement skill interventions and their effects (study I) in preschool children. Out of the findings of study I, and based on the literature review, physical fitness components, particularly muscle strength and power, as important facilitators of an optimal development of movement patterns, and cognitive performance (i.e., attention), were analyzed and the relationship between measures of physical fitness and cognitive performance in preschool children were investigated in study II. Hence, findings relating to the effectiveness of fundamental movement skill interventions and subgroup and exploratory analyses from study I, as well as the results of study II, were used to establish an exercise program for preschool children, focusing, particularly on muscle strength and power, coordination, and fundamental movement skills. This exercise program was implemented in kindergarten and preschool settings and included the education of kindergarten teachers and staff (study III).

The present thesis consists of a systematic review, one cross-sectional, and one longitudinal study, which are referred to with roman numbering in the following chapters:

Study I Wick, K., Leeger-Aschmann, C. S., Monn, N. D., Radtke, T., Ott, L. V., Rebholz, C. E., et al. (2017). **Interventions to Promote Fundamental Movement Skills in Childcare and Kindergarten: A Systematic Review and Meta-Analysis**. *Sports Medicine (Auckland, N.Z.)*, *47*(10), 2045–2068.

Study II Wick, K., Kriemler, S. & Granacher, U. (2022). **Associations between measures of physical fitness and cognitive performance in preschool children**. *BMC Sports Science, Medicine and Rehabilitation, 14(1)*, 80.

Study III Wick, K., Kriemler, S. & Granacher, U. (2021). **Effects of a Strength-Dominated Exercise Program on Physical Fitness and Cognitive Performance in Preschool Children**. *Journal of strength and conditioning research, 35*(4), 983–990.

4 Synopsis of methods

To analyze and discuss the research questions and hypotheses, this paragraph presents a short summary of the employed methods regarding the systematic literature review and meta-analysis, as well as a description of study designs, participants (samples), intervention programs, assessments, testing procedures, and statistical analyses of the two experimental studies. Detailed information about materials and methods is provided in the appendix (see studies I-III).

4.1 Systematical literature review and meta-analyses

To assess the effectiveness of fundamental movement skill interventions in childcare and kindergarten settings, a systematic literature search using 7 databases (CINAHL, Embase, MEDLINE, PsycINFO, PubMed, Scopus, and Web of Science) was conducted (see study I). Studies published in English or German featuring healthy children aged 2-6 years, that applied fundamental movement skill-enhancing interventions of at least 4 weeks and met the inclusion criteria, were extracted from the data bases. Furthermore, the systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2009). Further information and detailed procedures of the systematic review and of meta-analytical calculations are provided in the appendix (study I) (Wick et al., 2017).

4.2 Experimental studies

4.2.1 Participants

In total, 61 healthy children (boys n = 31; girls n = 30) aged 4-6 years from a convenience sample of 3 selected kindergartens located in the East German Federal State of Brandenburg participated in the two experimental studies. Prior to the commencement of the studies, parents or legal representatives of all participating children received written information on the aims, procedures, risks and benefits, and data collection with written informed consent subsequently obtained. In accordance with the latest version of the Declaration of Helsinki, these studies were approved by the Ethics Research Committee of the University of Potsdam, Germany (submission No. 34/2018). Detailed information about participants, methods, and the chosen study designs are presented in the original studies (studies II – III), as in the appendix (Wick et al., 2021, 2022).

4.2.2 Testing procedures

The tests were conducted at the kindergartens by the same trained assessors. The entire test program lasted between 20 and 30 minutes per child, whereby, every child was tested individually. The testing procedures included physical fitness testing (i.e., static balance, muscle strength, power, coordination), anthropometric (i.e., body height, body mass and BMI), and cognitive assessments (i.e., attention). All participating children received standardized verbal instructions and a visual demonstration regarding the test procedures before the test trial. Thereafter, each child performed a familiarization trial.

4.2.2.1 Physical fitness tests

To assess different physical fitness components in children aged 4-6 years, age-appropriate measurements like the handgrip strength test (muscle strength of the upper body) using a hand dynamometer, the standing long jump test (muscle power of the lower body), the single-leg stance test (static balance,) and the hopping on one leg test left/right (coordination) were chosen. Depending on the study, the four physical fitness components were analyzed separately (study II and III) or as a motor composite score (study II). Additionally, an overall measure of coordination was computed for the hopping on one leg left/right in study II. Precise information about testing procedures and details of validity traits and rehabilitee estimates of included physical fitness tests are reported in the appendix (studies II - III) (Wick et al., 2021, 2022).

4.2.2.2 Cognitive tests

Within this thesis, attention was applied with the *Konzentrations-Handlungsverfahren für Vorschulkinder* ("concentration-action procedure for preschoolers") (KHV-VK). Children had to sort 40 cards into 4 different boxes within 10 minutes according to different key images presented on the cards. The KHV-VK examines two dimensions of attention, a quantitative (working speed – sorting time) and a qualitative (working accuracy – error quote) dimension. More information about testing procedures and validity traits and rehabilitee estimates of the KHV-VK are reported in the appendix (studies II - III) (Wick et al., 2021, 2022).

4.2.3 Intervention

The effectiveness of a strength-dominated kindergarten-based intervention program which was developed by an exercise scientist and kindergarten teachers was evaluated using a 2-group repeated-measures design. The intervention period lasted 10 weeks, whereby three exercise sessions were conducted per week. On Monday, Wednesday, and Friday mornings' kindergarten teachers carried out the 30 minutes-exercise session within the premises of the sampled kindergartens. In summary, 30 sessions were implemented, focusing on the development of different components of physical fitness and motor skills. Contents of the 30 sessions included balance exercise (i.e., standing on one leg, balancing on ropes), coordination exercise (i.e., handling objects, moving like animals) in the form of small games and in particular, strength exercises (i.e., squats, planks). To complete the strength-dominated intervention program, basic elements of gymnastics (i.e., stretch seat, table position) were included. Overall, the structure of each session was basically the same, focusing on strength exercises as the main part of every single session. Detailed information on the intervention program and descriptions of the strength and gymnastic exercises are provided in the appendix (study III) (Wick et al., 2021). The control group (waiting group) performed the regular kindergarten curriculum, with one general exercise session per week (30-45 minutes) and at least one hour of free play per day.

4.2.4 Statistical analyses

Statistical analyses of this thesis were performed in accordance with the assumptions and research questions of the corresponding studies. Prior to the analytical calculations, normal distribution of data was tested using the Shapiro-Wilk test and descriptive analyses were performed and presented as group mean values and standard deviations (SD) (study II and study III). To determine significant baseline differences between the intervention and the control kindergartens according to anthropometric characteristics, a t-test for independent samples was calculated (study III). Correlations were computed using the "Pearson product-moment correlation coefficient" (r) and the "Spearman rank correlation coefficient" (r) (study II). The effects of a 10-weeks strength-dominated intervention program on different parameters of physical fitness (i.e., static balance, muscle strength, power, coordination) and cognitive performance (i.e., attention) were detected using a separate 2 (group: intervention kindergarten vs. control kindergarten) x 2 (time: pretest vs. post-test) repeated-measures analysis of covariance (ANCOVA). In the case of statistically significant "group x time" interaction effects, post hoc tests with Bonferroni-correction were calculated (study III). Additionally, single linear regression models for attention (composite score and two individual dimensions) and physical fitness (composite motor score) and a stepwise multiple linear regression model for the four measures of physical fitness were estimated separately (static balance, muscle strength, power, and coordination). Moreover, attention (composite score and two individual dimensions) was computed in kindergarten children aged 4-6 years. Thereby, age, body height, and body mass were included in the single regression model as covariates (study II). Subsequently, effect sizes (Cohen's *d*, Cohen's F, Cohen's F^2) were determined to ascertain if an effect was practically meaningful (study II and study III). All statistical analyses were performed using SPSS version 25.0 (IBM SPSS Statistics, Armonk, NY, USA). Detailed information about all statistical analyses can be found in the appendix (see study II - III) (Wick et al., 2021, 2022).

5 Synopsis of results

This thesis comprises three studies. It consists firstly of a systematic review with meta-analysis to assess the effects of fundamental movement skill interventions in childcare and kindergarten settings. Secondly, an explorational study analyzing the relationship between physical fitness and cognitive performance in kindergarten children aged 4-6 years is reported. Thirdly, an intervention study focusing on strength-dominated and gymnastic-based exercises to investigate the training-related changes in physical fitness and cognitive performance of the same sample is included. Chapter 5 summarizes the main results of the three peer-reviewed and published studies, which are attached in full length in the appendix (see studies I – III).

5.1 Study I: Interventions to promote fundamental movement skills in childcare and kindergarten: A systematic review and meta-analysis

Overall, 30 trials (15 randomized controlled trials and 15 controlled trials) out of 17,566 identified records were eligible. The findings revealed that fundamental movement skill programs are effective in children aged 3.3–5.5 years, reflecting significant differences among groups in favor of the intervention group with small to large effects on overall motor skill proficiency (total FMS score weighed mean $SMD_{between}$ 0.46, 95% CI 0.28–0.65; I^2 = 83%), as well as on object control (weighed mean $SMD_{between}$ 1.36, 95% CI 0.80–1.91; I^2 = 94%) and on locomotor skills (weighed mean $SMD_{between}$ 0.94, 95% CI 0.59–1.30; I^2 = 88%,). Moreover, studies of shorter duration (less than 6 months) compared to longer duration (more than 6 months) resulted in higher effect sizes in overall fundamental movement skills. In contrast, the methodological quality of included studies showed no statistically significant differences in effect sizes. Further analyses demonstrated statistically significant higher effect sizes on overall fundamental movement skills (weighed mean $SMD_{between}$ = 1.46, 95% CI 0.52–2.40) in childcare contexts or kindergartens where external experts implemented the intervention programs compared to facilities where childcare or kindergarten teachers were responsible for implementation. Nevertheless, the results of this systematic review and meta-analysis must be interpreted with care due to low certainty in treatment estimates based on GRADE.

<u>Study I was published as follows:</u>

Wick, K., Leeger-Aschmann, C. S., Monn, N. D., Radtke, T., Ott, L. V., Rebholz, C. E., et al. (2017). Interventions to Promote Fundamental Movement Skills in Childcare and Kindergarten: A Systematic Review and Meta-Analysis. *Sports Medicine (Auckland, N.Z.)*, *47*(10), 2045–2068. IF: 7.074

5.2 Study II: Associations between measures of physical fitness and cognitive performance in preschool children

The results of the regression analyses indicated that physically fitter preschool children have significantly better attentional capacity than less fit children, showing medium correlations with a significant small to medium effect ($F^2 = 0.14$) for the relation of physical fitness (motor composite score) and the composite score of attention (standardized ß = 0.40; $p < 0.05$). Furthermore, in accordance with the study hypothesis, only coordination as measured by the hopping on one leg test illustrated significant medium correlations with the composite score (standardized ß = 0.35; $p < 0.01$) and the quantitative dimension (standardized ß = -0.33; $p < 0.05$) of attention. The physical fitness component coordination explained about 11% (composite score) and 9% (quantitative dimension) of the variance of attention, returning small-medium effect sizes ($F^2 = 0.12$; $F^2 = 0.10$).

<u>Study II was published as follows:</u>

Wick, K., Kriemler, S. & Granacher, U. (2022). Associations between measures of physical fitness and cognitive performance in preschool children. *BMC Sports Science, Medicine and Rehabilitation, 14* (1), 80. IF: 1.934

5.3 Study III: Effects of a strength-dominated exercise program on physical fitness and cognitive performance in preschool children

the children in the intervention group ($p < 0.001$; $d = 1.53$) showed significantly better results for the standing long jump test (muscle power of the lower extremities) compared to those in the control group ($p = 0.72$; $d = 0.83$) after a 10-week exercise program. No statistically significant interaction effects were found for other physical fitness components (static balance, muscle strength, coordination). In addition, an applied intervention program in the kindergarten setting seemed to be effective in significantly improving the quantitative dimension of attention (working speed) in young children ($p < 0.001$; $d = 1.69$), when compared to a regular kindergarten curriculum ($p = 0.27$; $d = 0.52$).

<u>Study III was published as follows:</u>

Wick, K., Kriemler, S. & Granacher, U. (2021). Effects of a Strength-Dominated Exercise Program on Physical Fitness and Cognitive Performance in Preschool Children. *Journal of strength and conditioning research, 35*(4), 983–990. IF: 3.775

6 General discussion

Within the scope of this thesis, the focus was set on motor and cognitive performance during the preschool years. To approach the topic, a systematic literature review with a meta-analysis was chosen as first step, in order to analyze the effectiveness of overall exercise and fundamental movement skill interventions on fundamental movement skills in kindergarten and preschool children was conducted (study I). Thereafter, a cross-sectional (study II) was utilized to investigate the relationships between different components of physical fitness and attention as one domain of cognitive performance. Subsequently, a longitudinal study (study III) was carried out to develop an age-appropriate, joyful, and feasible intervention program to promote both, motor and cognitive development in healthy children aged 4-6 years attending kindergarten or preschool settings.

6.1 Promotion of exercise and fundamental movement skills

In general, the results of this research revealed that exercise and fundamental movement skill interventions implemented in kindergarten, preschool, or childcare settings are an effective method to promote overall proficiency in motor skills (i.e., object control and locomotor skills) in preschool children. The respective analyses produced small to large effect sizes (study I). Nonetheless, it has to be mentioned that these findings have to be interpreted with care due to the low certainty of evidence based on GRADE. Overall, there is a need for more methodologically sound research (van Sluijs & Kriemler, 2016) as this thesis revealed several methodological weaknesses of the currently existing studies that should be avoided when conducting research in the field of exercise, physical fitness, and fundamental movement skill interventions in early childhood. Room for improvement exists with regard to the integration of power analyses prior to study commencement in order to calculate (and achieve) sample sizes needed for group or sub-group analyses (Faul et al., 2007). Moreover, standardized randomization procedures, the blinding of assessors for outcome measures (Hróbjartsson et al., 2013; Wood et al., 2008), standardized assessment tools for outcome measures which are precisely selected based on the research questions (Hulteen et al., 2020; Logan et al., 2017; Lopes et al., 2020), the use of adequate statistical methods (i.e., appropriate baseline comparisons, control for confounders and clusters (Campbell et al., 2012)), and finally, the assessment of intervention fidelity (Miller & Rollnick, 2014) by detailed reporting of intervention contents, intensity, and load factors as well as physical activities of the control group, need to be taken into consideration more carefully in future research.

In contrast to the study hypothesis, further meta-analytical calculations revealed that studies of shorter duration (< 6 months) compared with longer duration (> 6 months) were more effective. A possible explanation could be that a loss of motivation and compliance appeared among children and kindergarten teachers as a consequence of monotonous intervention contents (Lai et al., 2014), as well as insufficient training progression due to low or steady intensity and/or load factors (Faigenbaum et al., 2011). These results are in line with findings from other reviews (Logan et al., 2012). In contrast to the second hypothesis, the methodological quality of included studies did not play a role for the effectiveness of interventions, which indicate that an overestimation of training on fundamental movement skills in preschoolers did not occur.

Harter (1980) postulated that the success of fundamental movement skill interventions in kindergarten or preschool settings significantly depends on the integration of experts who bring detailed knowledge about motor and cognitive development in children as well as training competencies (i.e., pedagogical skills, expertise in developing age-appropriate, joyful exercise programs) to promote fundamental movement skills but also to train self-confidence and, therefore, strengthen perceived motor competence in children (Robinson & Goodway, 2009). Self-confidence and perceived motor performance, besides competencies in fundamental movement skills, are critical factors for the acquisition of more complex and sport-specific skills (Seefeldt, 1980; Stodden et al., 2008), the engagement in various leisure time, organized or competitive sports, and an active lifestyle (Wrotniak et al., 2006). In this regard, further exploratory analysis revealed that the integration of external experts rather than the implementation of the programs by the usual kindergarten or preschool teachers resulted in higher effect sizes. In summary, exercise programs for children have to be appealing, age-appropriate, and joyful, including individual performance progression (i.e., success in fundamental movement skills and/or physical fitness), to gain and maintain a child’s interest (van Sluijs & Kriemler, 2016) in physical activities.

The results of the systematic literature review in study I and the gained knowledge regarding the methodological quality of included intervention studies, duration of intervention programs, and the inclusion of external experts, served as valuable indications during the present thesis and were integrated into further processes of the conceptual set up of study II and study III.

6.2 Role of physical fitness on cognitive performance

Study I provided a systematic overview of the effects of fundamental movement skills and exercise interventions on actual fundamental movement skills in preschool children and served as an entrance into the research field. Study II was established to further deepen the knowledge of motor and cognitive performance and their interrelatedness. Rapid brain maturation occurs during early ages, exhibiting equally protracted developmental timetables for motor and cognitive development (Diamond, 2000; Gogtay et al., 2004). The findings of this thesis are partly in line with several cross-sectional research studies done on preschool children. The existing literature shows that physically fitter preschool-aged children (composite score of physical fitness) showed significantly better attentional capacity (composite score) than less fit children with a significant small-medium effect ($F^2 = 0.14$) (Wick et al., 2022).

Yet, there are no available studies reporting associations on a total motor score and attention (composite score, individual dimensions of attention separately) in preschool children, although significant correlations have been found between composite motor scores of physical fitness and domains of cognitive performance other than attention (e.g., visuospatial working) in preschoolers (Davis et al., 2011; Greier & Drenowatz, 2019). Furthermore, in accordance with the hypothesis, the results showed that complex fitness components (i.e., coordination) which require higher order cognitive skills during execution are more strongly related to attention compared to simple fitness components (i.e., muscle strength). In study II, coordination assessed by the hopping on one leg test explained about 11% (composite score) and 9% (quantitative dimension – sorting time) of the variance of attention with a weak to medium effect size. Van der Fels et al. (2015) and Schmidt et al. (2016) reported similar findings, illustrating that coordination and complex exercises (i.e., fine motor skills, bilateral body coordination, and speed of movement (e.g., foot tapping, running in a zigzag)), and games improve cognitive performance (i.e., memory, visual processing, executive functions, and fluid intelligence) to a higher extent than plain repetitive aerobic tasks (e.g., to reach recommended daily physical activity guidelines only) in children. Thereby, the hopping on one leg test is a complex and demanding exercise measuring dynamic balance, muscle strength, muscular endurance, bilateral body coordination, and coordination of rhythm. While hopping, motor control and motor regulation are constantly needed and lead to co-activations between different parts of the central nervous system (Diamond, 2000). Best (2010) and Tomporowski et al. (2011; 2015) argued that cognitively demanding exercises require higher cognitive effort which may stimulate motor and cognitive performance (i.e., attention, especially working speed as one dimension) simultaneously, as illustrated in study II.

Subsequently, the other fitness components (e.g., static balance, muscle strength, and power) analyzed in study II were not related to attention and were thus excluded from the stepwise multiple regression model. These findings are in accordance with other studies focusing on the relationship between dynamic balance (i.e., balancing backwards) and attention (Niederer et al., 2011), muscle power (i.e., standing long jump) and visuospatial working (Greier & Drenowatz, 2019), and muscle power (i.e., standing long jump) or handgrip strength and visual processing (Voelcker-Rehage, 2005) in preschool children. As a possible explanation of the null results, the authors presumed that these above-mentioned tasks were less complex, simpler to execute, and therefore less cognitively demanding.

It seems that physical fitness as a theoretical construct is measured indirectly using quantitative (product-oriented) assessment tools which require a certain level of fundamental movement skills (i.e., single leg stance test, standing long jump test, hopping on one leg test). If children cannot proficiently run, jump, and hop they will not experience success in movement activities but, moreover, it will be challenging to accurately measure physical fitness parameters (Gallahue et al., 2012; Ortega et al., 2015), which could also explain the null results of study II.

Lastly, the reported statistically significant associations between physical fitness (composite motor score) and attention (composite score), as well as those between coordination separately and attention (composite score and quantitative dimension) in study II, underline the close relationship in developmental trajectories in motor and cognitive development based on high neuroplasticity of the central nervous system during childhood (Diamond, 2000; Gogtay et al., 2004). Accordingly, the results of studies I and II are the foundation of further research questions of this thesis to promote both motor and cognitive performance in preschool children and, therefore, generate a healthy upbringing.

6.3 Effects of strength-dominated exercises on physical fitness and cognitive performance

Fundamental movement skill interventions in preschool children have proven to be effective (study I), but with the restriction that a low certainty of evidence had to be constituted because of methodological weaknesses of intervention studies (Wick et al., 2017). Furthermore, as physical fitness is related to many health benefits (Ortega et al., 2008), enhances and facilitates motor performance (Faigenbaum & Bruno, 2017; Myer, Faigenbaum et al., 2013), and reduces the risk of sustaining sports-related injuries (Faigenbaum et al., 2016; Myer et al., 2015), it should be a focus of physical activity and exercise interventions besides motor skill learning in preschool children. Thereby, Lloyd and Oliver (2012) emphasized the importance of muscle strength at all developmental stages, starting in early childhood. The cross-sectional results of study II further demonstrate that physically fitter preschool-aged children exhibit significantly better attentional capacity than their less-fit counterparts. These associations were analyzed further in study III, including a longitudinal study design to discover possible cause-and-effect relationships.

This thesis found statistically significant effects of a 10-week kindergarten-based intervention program focusing especially on muscle strength and gymnastic exercises in healthy kindergarten and preschool children (Wick et al., 2021). The respective (findings on the) effects were in accordance with the study's hypotheses. Moreover, the findings indicate that 3 exercise sessions per week (Monday, Wednesday, Friday) over a 10-week period induced a significant large effect ($d = 1.09$) for the primary outcome of muscle power of the lower body (i.e., successfully developing jumping performance) and a near to significant medium effect ($d = 0.58$) for the secondary outcome attention (i.e., tend to improve attentional capacity) compared to usual kindergarten curriculum, which included one exercise session per week (30–45 minutes) and at least one hour of free play per day. Similar significant findings for the standing long jump ($p < 0.05$, $d = 0.51$) were reported by Popovic et al. (2020) for a 9-month structured multisport program (2 x 60 minutes per week) conducted with preschool children. Contents of the multisport program varied but focused particularly on stability (trunk strength), locomotor (running, hopping, and jumping), or manipulation (ball skills) (Popović et al., 2020). A meta-analysis by Behringer et al. (2011) also found significant improvements in jump performance after structured strength training programs but for school-aged children. For the other physical fitness outcomes (muscle strength, static balance, coordination) of study III, no significant intervention effects could be found, although physical activity, multisport, and exercise programs in primary school and kindergarten children have been shown to be effective in improving muscle strength of the upper body (i.e., measured with the push-up test (Faigenbaum et al., 2015) or the bent arm hang test (Popović et al., 2020)), static balance (i.e., measured with the single-leg stance test (Kordi et al., 2016; Roth et al., 2015)), and coordination (i.e., assessed with the hopping one leg test (Krombholz, 2012)). Of note, the specific training content and design of the implemented strength-dominated intervention program in study III concentrating on muscle strength (of upper and lower body), core strength, and overall coordination may explain these null results (Wick et al., 2021). However, as biological maturation and growth occur constantly and quickly during childhood and influence physical fitness levels (Malina, 2014), overall time effects for the handgrip strength test, the single-leg stance test, and the hopping on left leg test can be reported for the control group in study III.

Regarding the outcomes of cognitive performance, this thesis indicates that higher levels of physical fitness may foster a child's attention. Moreover, already younger children of kindergarten age appear to respond to regularly offered exercise programs, with the focus particular on muscle strength (upper, lower limbs, core) by improving their attentional capacity (study III). These findings are in line with results from Fedewa and Ahn (2011), who illustrated that regular concurrent performance of aerobic exercise and perceptional motor training (3 x week) over 36 weeks (academic school year) has the potential to improve not only cardiorespiratory endurance (i.e., aerobic fitness), but also cognitive (e.g., intellectual quotient) and academic performance (e.g., math and reading achievement) in school-aged children. Additionally, Niederer et al. (2011) demonstrated that fitness level at preschool age is related to future performance in attentional capacity at school age. Similar findings have been reported by Alavi et al. (2019) and Pagani et al. (2012), showing that attention in preschool age predicts academic achievement in the long term during the school years. Attention is a fundamental skill for learning and academic achievement in educational contexts (Hampton Wray et al., 2017; McClelland et al., 2013) and will prepare children for school, the specific learning conditions at school (focus attention, listening, understanding, sitting still) (Perera, 2005), and goal-directed and adequate social behavior. Thus, additional regular physical activity and exercises (e.g., care-based intervention programs), as demonstrated in this thesis, tend to positively influence brain development and may affect academic performance later in life (Álvarez-Bueno et al., 2017; Diamond & Ling, 2016).

Lastly, Faigenbaum and Bruno (2017) stated that the early age is assumed to be the opportune time to promote age-appropriate and joyful exercise interventions to enhance physical fitness and facilitate motor skill learning and cognitive development, and the findings of this thesis underline this fact by showing that preschool-aged children are responsive to adequate exercise stimuli (i.e., strength-dominated and coordination exercises) if supported by professional instruction and feedback (Tomporowski et al., 2015; van Sluijs & Kriemler, 2016).

7 Study limitations

This thesis comprised of a systematic literature review with a meta-analysis, a cross-sectional study, and a longitudinal study, to investigate the role of motor and cognitive performance in healthy kindergarten or preschool children. Based on the systematic literature review (study I) and the longitudinal study (study III), effects of fundamental movement skill and exercise interventions on motor skills, physical fitness (i.e., static balance, muscle strength, power, coordination) and cognitive performance (i.e., attention) could be demonstrated at an early age. Furthermore, the cross-sectional study (study II) indicates that there is a close relation between physical fitness, in particular coordination, and attention in 4 to 6-year-old children. However, the results of the present thesis must be critically evaluated to detect possible limitations of the published studies (I-III).

In reference to study I, large heterogeneity of meta-analytical results and very low certainty for the intervention effects are important limitations due to a huge variation in intervention content, duration, intensity, load and physical activity strategies, poorly described or defined physical activities of the control group, as well as a wide range of motor skill assessment tools to measure motor skills (Hulteen et al., 2020; Logan et al., 2017) of many eligible studies (Wick et al., 2017). GRADE (Guyatt et al., 2013) suggested converting results of different motor skill assessment tools among the eligible studies of the systematic review to the most commonly used tool (e.g., TGMD-2) which may have led to important between-study heterogeneity (Puhan et al., 2006).

Moreover, to critically discuss the eligibility criteria, only studies published in English or German were included in the review, irrespective of the fact that high quality research studies also exist in other languages. Of note, since study I was published in 2017, several research articles examining the effects of fundamental movement skill and physical fitness interventions, especially in healthy preschool children (i.e., (Birnbaum et al., 2017; Bruno & Faigenbaum, 2019; Latorre-Román et al., 2018; Mačak et al., 2022; Okely et al., 2020; Popović et al., 2020)), have been published over the last 5 years showing the huge interest in young children and the strong intentions to widen the knowledge of motor development in childhood.

Regarding the cross-sectional and longitudinal studies, participating children were selected from three kindergartens located in East Germany (i.e., the Federal State of Brandenburg) through convenience sampling, which constitutes a relatively small none-representative sample. These kindergartens (i.e., teacher, staff, parents) may have already been aware of the importance of adequate physical fitness levels and optimal developed motor skill competencies for a healthy upbringing of their children as they already offered programs for the promotion for physical activity and fitness and declared their interest to take part in the present study more than others did.

Notably, the results of this thesis (cross-sectional and longitudinal) evaluated only one-directional relations of physical fitness on attention as well as the effects of an exercise program (i.e., strength-dominated kindergarten-based) on physical fitness and attention. Moreover, study II and III included anthropometric data as covariates only to examine the relationship of physical fitness and attention in preschool children, no more effect modifications (e.g., gender, socio-demographic, socio-economic background, parent's attitude towards physical activity, children's physical activity behavior) were assessed.

It must be mentioned that study I explicitly investigated the effects of exercise interventions on fundamental movement skills measured mainly with process-orientated assessment tools (e.g., TGMD-2). In contrast, study II and III concentrated on physical fitness components measured with product-orientated assessment tools. Although, process- and product-orientated assessment tools are related to some extent (Logan et al., 2017; Palmer et al., 2021) as both measure aspects of motor performance, it has to be noted that variation of correlations across the different instruments have been reported in the literature (Cools et al., 2009; Logan et al., 2011).

8 Practical relevance and future directions

The aim of this thesis was to investigate motor and cognitive performance in typically developing preschool children. By analyzing the effects of fundamental movement skill interventions on actual fundamental movement skills, the intention was to examine the associations of physical fitness components, in particular muscle strength, power, and coordination, on attention as one domain of cognitive performance. Based on the respective evidence, the elaboration and implementation of a feasible and sustainable strength-dominated exercise program which includes various elements of gymnastics in kindergarten and preschool settings was conducted and evaluated. The findings indicate improvements in fundamental movement skills, physical fitness (i.e., muscle power), and cognitive performance (i.e., attention – quantitative dimension – working speed) in subsequent exercise programs (i.e., fundamental movement skill interventions, strength-dominated and coordination exercises) implemented at kindergarten or preschool settings. Moreover, physical fitness exercises which are complex, cognitively demanding (i.e., coordination tasks), and require permanent motor control and motor regulation, may positively interact with cognitive tasks (Myer et al., 2015; van den Berg et al., 2019; van der Fels et al., 2015). Additionally, the participating kindergarten teachers of study III reported that the strength-dominated exercise program resulted in improved psychosocial behavior, particularly in younger (4 years) children showing the positive effect of exercise and physical activity not only on physical fitness components, motor skill learning, and cognitive performance but also on social and psychological behavior. As this finding was not measured objectively, future research studies should focus on this outcome measure as well.

To substantiate the results of the present cross-sectional and longitudinal study, it is suggested that future studies should include a larger randomly selected representative sample size to examine cause-effect relationships between physical fitness and attention at the preschool age. Furthermore, it would be an interesting subject of scientific research to examine the reversed relation of cognitive performance (i.e., attention) on physical fitness and fundamental movement skills, as well as the effects of a cognitively demanding training program on motor performance.

Given that a large number of children attending kindergarten or preschool can be reached very early, irrespective of their family’s socioeconomic background and without stigmatization of children who need it most, the results of the present thesis provide important preventive and supportive strategies for parents and practitioners in particular (i.e., kindergarten and preschool teachers) as those provide appropriate delivery of intervention contents with professional instruction, feedback, and interaction. Moreover, the integration of an external expert could be beneficial (Robinson & Goodway, 2009) regarding intervention effects. However, it is a substantial task to qualify and educate members of the kindergarten staff and get them involved in the preparation and implementation of physical activity programs, yet this may sharpen the awareness of the topic (van Sluijs & Kriemler, 2016), lead to intrinsic motivation, and subsequently, create sustainable long-term effects as these physical activity and exercise programs will be included in the daily kindergarten curriculum. In terms of the contents of exercise programs, the implementation of muscle strengthening exercises already at preschool age is crucial to build a solid foundation of muscular fitness (i.e., muscle strength, muscle power, local muscular endurance), which is a prerequisite for motor skill learning and other physical fitness components (i.e., balance, coordination, speed) (Faigenbaum & Bruno, 2017). Thus, it should be a prioritized public health strategy, to further educate kindergarten teachers to enable them to carry out regular age-appropriate, attractive, joyful, effective physical activity, and exercise programs. Staff and teachers are to some extent role models, and as such may influence the motor and cognitive development of children. Secondly, it is important to enhance public and political awareness for the important role of physical activity of children. Subsequently, political decision makers and public health institutions should advise preschools, kindergartens, and childcare centers to implement compulsory regular physical activity sessions during the week.

Physical activity behavior of children has changed and a decline in daily physical activity (Farooq et al., 2018) in primary school children is noticeable mostly due to low motor skills competencies (Hardy et al., 2012; Hardy et al., 2013; Roth et al., 2010), as well as low levels of physical fitness (Fühner et al., 2021; Masanovic et al., 2020; Tomkinson et al., 2019). Thus, it is more important than ever to concentrate on a broad foundation of fundamental movement skills and physical fitness in preschool-aged children. More specifically, if children cannot proficiently run, jump, hop, throw, and catch (i.e., Seefeldt's (1980) postulated "proficiency barrier") they do not experience success in movement activities, and as a consequence suffer from reduced levels of physical fitness. This again may lead to lower motivation to participate in physical activity and will continuously lead to negative interactions between low motor competence, less physical activity (hypoactivity), and lower physical fitness (e.g., Myer and colleagues' (2013) described "exercise deficit disorder").

Nevertheless, future theory-driven research studies should focus on well-designed evaluations of well-defined interventions in order to address current limitations. These should include the continuous need to focus on the most effective intervention components as well as the intervention compliance (Martins et al., 2015; Robinson et al., 2015). Regarding the assessment of motor performance, standardized measurements for preschool children, combining both process- and product-oriented assessment tools (Logan et al., 2017; Palmer et al., 2021), should be used, including international reference values to understand and define possible intervention effects (van Sluijs & Kriemler, 2016).

Lastly, as physical activity and fitness tend to track from childhood into adulthood (Kristensen et al., 2008; Telama et al., 2014), it seems that physically inactive children are more likely to become physically inactive adults (Telama et al., 2005), and physically inactive parents tend to raise physically inactive children (Yao & Rhodes, 2015). Thus, the promotion of physical activity and exercise intervention programs for a healthy motor and cognitive development in the long-term is even more effective if started at the preschool age.

9 References

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Study I

Interventions to Promote Fundamental Movement Skills in Childcare and Kindergarten: A Systematic Review and Meta-Analysis

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Abstract

Proficiency in fundamental movement skills (FMS) lays the foundation for being physically active and developing more complex motor skills. Improving these motor skills may provide enhanced opportunities for the development of a variety of perceptual, social, and cognitive skills. The objective of this systematic review and meta-analysis was to assess the effects of FMS interventions on actual FMS, targeting typically developing young children. Searches in seven databases (CINAHL, Embase, MEDLINE, PsycINFO, PubMed, Scopus, Web of Science) up to August 2015 were completed. Trials with children (aged 2–6 years) in childcare or kindergarten settings that applied FMS-enhancing intervention programs of at least 4 weeks and meeting the inclusion criteria were included. Standardized data extraction forms were used. Risk of bias was assessed using a standard scoring scheme (Effective Public Health Practice Project—Quality Assessment Tool for Quantitative Studies [EPHPP]). We calculated effects on overall FMS, object control and locomotor subscales (OCS and LMS) by weighted standardized mean differences ($SMD_{between}$) using random-effects models. Certainty in training effects was evaluated using GRADE (Grading of Recommendations Assessment, Development, and Evaluation System). Thirty trials (15 randomized controlled trials and 15 controlled trials) involving 6126 preschoolers (aged 3.3–5.5 years) revealed significant differences among groups in favor of the intervention group (INT) with small to-large effects on overall FMS ($SMD_{between}$ 0.46), OCS ($SMD_{between}$ 1.36), and LMS ($SMD_{between}$ 0.94). Our certainty in the treatment estimates based on GRADE is very low. Although there is relevant effectiveness of programs to improve FMS proficiency in healthy young children, they need to be interpreted with care as they are based on low-quality evidence and immediate post-intervention effects without long-term follow-up.

Introduction

Fundamental movement skills (FMS) are basic abilities and skills of a child to perform an organized series of basic movements that involve various body parts and provide the basis of achieving a high level of motor competence to develop normally, maintain health, and gain athletic excellence (Gallahue & Ozmun, 2006; Haywood & Getchell, 2003; Lloyd et al., 2015; Lloyd et al., 2016; Payne & Isaacs, 2012). FMS is usually classified into basic locomotor skills that enable children to transfer the body in space (e.g., walking, running, jumping, sliding, hopping, and leaping), and object control skills that enable them to manipulate and project objects (i.e., throwing, catching, striking, bouncing, kicking, pulling, and pushing) (Barnett et al., 2009; Burton & Miller, 1998; Cools et al., 2009). Although locomotor and object control subscales (LMS and OCS) are reasonably well correlated ($r = 0.84–0.96$) (Cools et al., 2009), they should be differentiated, given their discrete and independent importance towards predicting health behaviors (Robinson et al., 2015). FMS are essential to the more specialized and complex skills used in play, games, and sports. Mastery of these basic motor skills that predominantly evolve during the preschool years (Cools et al., 2009; Stodden et al., 2008) is an essential part of pleasant participation and a lifelong interest in a physically active lifestyle (Lubans et al., 2010; Seefeldt, 1980), or even of becoming an elite athlete (Lloyd et al., 2015). Proficiency in FMS is considered critical to achieving and maintaining physical activity (Logan et al., 2015; Lubans et al., 2010) and physical fitness (Cattuzzo et al., 2016), preventing obesity (Barnett et al., 2016) (D'Hondt et al., 2013; D'Hondt et al., 2014), and developing more complex motor skills for later life (Robinson et al., 2015; Stodden et al., 2008). Yet, an increasing number of young children have insufficiently developed FMS (Bryant et al., 2014; Erwin & Castelli, 2008; Hardy et al., 2013). Given that FMS are related to lifelong engagement in physical activity that is essential not only to maintain physical health, but likewise to support cognitive and social development during childhood (Haapala, 2013), it is important to promote FMS during the first years of life (Lubans et al., 2010). The acquisition of FMS is not only achieved through natural development and maturation, but also through continuous interaction with a stimulating and supportive social and physical environment including attractive and sufficient space, a stimulating social attitude, as well as a professional instructional approach. This concept is based on a mutual interaction between the biological conditions and the environment that can be seen as a dynamic developmental system of perception and action (Gabbard, 2009). This prepares children to engage in a wide and complex range of physical activities (Barnett et al., 2009; Williams et al., 2008) that induces adaptive neuro-motor development, and hence FMS (Robinson et al., 2015; Stodden et al., 2008). Based on the conceptual models introduced by Stodden et al. (2008) and Robinson et al. (2015), there is likely a bidirectional interaction between actual FMS and physical activity, with the association also being mediated by perceived FMS (Babic et al., 2014) and physical fitness (Cattuzzo et al., 2016). Although important, this mediating role is yet insufficiently studied in young children (Robinson et al., 2015) and therefore not in the scope of this review.

In the past, several reviews have covered the effects of FMS intervention programs on FMS in children. However, those articles either examined healthy school-aged children (Lai et al., 2014; Morgan et al., 2013), children with motor disabilities or handicaps (Pless et al., 2000; Smits-Engelsman et al., 2013), or focused on physical activity (Ling et al., 2015; Mehtälä et al., 2014), which is clearly different from FMS. The two reviews with a similar scope to ours included primarily healthy preschool children and were published 5–7 years ago (Logan et al., 2012; Riethmuller et al., 2009). Although both found that interventions were effective in improving FMS, these articles were methodologically limited and therefore failed to provide solid evidence of the effectiveness of FMS intervention in preschool children. One of these systematic reviews (Riethmuller et al., 2009) included 17 studies with an intervention duration of 6–24 weeks. Sixty percent of the included studies showed statistically significant intervention effects. However, the authors did not conduct a meta-analysis due to the low methodological quality and the large heterogeneity of the included studies. The other review (Logan et al., 2012) included 22 studies that were primarily conducted in preschoolers. Findings showed that FMS interventions of 6–35 weeks' duration produced effect sizes in the range of 0.39–0.45 for overall FMS, OCS, or LMS. However, these authors did not perform any form of quality rating of the included studies. Further, uncontrolled studies were assessed, and the meta-analysis was computed based on pre-post values of the intervention groups only.

Due to this gap in the literature, the objective of this systematic review and meta-analysis was to describe and evaluate long-term effects (≥ 4 weeks) of childcare- and kindergarten-based intervention programs aiming to improve FMS in typically developing children during early childhood (ages 2–6 years). We used the Grading of Recommendations Assessment, Development, and Evaluation System (GRADE) to define certainty in effect estimates for the main outcomes. We further performed subgroup analyses to tease out whether quality, duration of the studies, or the type of teacher (e.g., childcare or kindergarten staff) influenced results. Finally, we performed exploratory analyses to identify interventions that were more effective than others by assessing differences in effect sizes according to type of FMS test used, target groups (e.g., gender), the setting (e.g., childcare versus kindergarten), or intervention characteristics (e.g., duration of the intervention).

Methods

We conducted and reported this systematic review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2009).

Literature search

A librarian experienced in running systematic literature searches carried out a tailored literature search of papers on interventions to promote FMS using CINAHL, Embase, MEDLINE, PsycINFO, PubMed, Scopus and Web of Science from the year of the inception of each database through August 2015 (Electronic Supplementary Material [ESM] Table S1). Based on the PICOS approach (Liberati et al., 2009), our search strategy focused on Population (e.g., children, preschoolers), Intervention (e.g., any type of intervention aiming at increasing FMS and reporting duration, frequency, and dose), Comparator (control group [CON] with usual childcare or kindergarten), Outcome (e.g., motor skills, running, hopping, balance skills), and Study design (e.g., controlled trial [CT], randomized controlled trial [RCT]). A repeated and broadened search approach was conducted after we retrieved a different set of eligible papers in our first searches with strategies that were too focused (e.g., preschoolers versus children, different exclusion criteria based on disease as motor handicaps or chronic disease rather than developmental delay), or too narrow (e.g., search options for the study design such as controlled study versus controlled trial or controlled intervention). Reference lists of included studies and published reviews were screened for additional potentially relevant articles.

Eligibility criteria

Eligible studies were either clustered or unclustered CTs or RCTs that enrolled preschool children aged 2–6 years without major health problems or motor handicaps/disability and assigned them to an intervention (INT) or a control (CON) arm with the specified aim of improving FMS. The intervention needed to take place in a common institutional setting where children of this age range spend their days (e.g., childcare, nursery, preschool, or kindergarten settings), irrespective of whether they belonged to the school or preschool system, with the aim of improving FMS proficiency. The duration of the intervention had to be at least 4 weeks as we were not interested in short-term effects. Further, the trial had to report a standardized motor skill outcome measure (preferably baseline and post-test or pre-post delta values—means, standard deviation [SD], and standard error [SE]) in both arms (INT and CON). We excluded studies not written in English or German, where only the abstract was available, and also trials that enrolled fewer than ten children because of the limited information that we would gain from such small sized studies.

Study selection and data extraction

Teams of reviewers (CL, KW, LO, NM, SC, SK) worked independently and checked in pairs the eligibility status of identified citations by screening titles, abstracts, and then the full paper. In case of any disagreement, consensus was reached through discussions and also by including a third person. The

reviewers used a pretested standardized form to extract information from each eligible study including
participants and cluster demographics, intervention details, study methodology, and outcome data. We collected primary outcome data that comprised any measured single motor skill task, composite overall (total FMS), or subscale scores (OCS, LMS) of motor skills. Studies used a wide range of methods to assess FMS (ESM Table S2) and reported a variety of different outcome measures. Other outcome measures (i.e., physical activity and body composition) are not discussed here but are described in Table 1.

Risk of bias assessment

The reviewers assessed the risk of bias of each eligible study using a slightly adapted version of the established 'Effective Public Health Practice Project Quality Assessment Tool for Quantitative Studies' (EPHPP) that has been proven valid in assessing Public Health interventions (Deeks et al., 2003) (ESM Table S3). This quality assessment tool rates study procedures as 'strong', 'moderate', or 'weak' using eight scales (selection bias, study design, confounders, blinding, data collection methods, withdrawal/dropouts, intervention integrity, and analyses). The same procedure was always applied. That is, two reviewers from a group of four (CL, LO, NM, SK) independently scored the items for each study as 'strong', 'moderate', or 'weak'. In cases of disagreement, consensus was reached by discussion or third-party arbitration. We provided an overall 'strong' or 'high quality' score if no 'weak' item score existed and at least four of the eight items were 'strong'. An overall 'moderate quality' score was provided with only one 'weak' item score and otherwise only 'strong' and 'moderate' item scores. The remaining studies were overall rated 'weak' or 'low quality'. The reviewers were not blinded to names of authors, institutions, journal, or the outcomes of the trials.

Missing data

We contacted the authors of fourteen studies (Bellows et al., 2013; Deli et al., 2006; Donath et al., 2015; Hamilton et al., 1999; Hardy et al., 2010; Ignico, 1991; Kelly et al., 1989; Krombholz, 2012; Piek et al., 2013; Reilly et al., 2006; Tsapakidou et al., 2014; Wang, 2004; Weiß et al., 2004; Zask et al., 2012) to obtain missing information about the FMS assessments (means of standard or raw scores of single FMS items, OSC, LMS, total scores, SD, and number of participants who took part in INT and CON) to be able to conduct our meta-analysis. Of those, six authors answered (Bellows et al., 2013; Donath et al., 2015; Hardy et al., 2010; Krombholz, 2012; Piek et al., 2013; Zask et al., 2012) and provided detailed information on the requested data. One author answered but could not help (Hamilton et al., 1999), and seven authors (Deli et al., 2006; Ignico, 1991; Kelly et al., 1989; Reilly et al., 2006; Tsapakidou et al., 2014; Wang, 2004; Weiß et al., 2004) did not respond to our repeated requests. Of those, three studies (Ignico, 1991; Reilly et al., 2006; Tsapakidou et al., 2014) provided total FMS scores in the original article that could be included in some, but not all metanalytical calculations. The other four studies (Deli et al., 2006; Kelly et al., 1989; Wang, 2004; Weiß et al., 2004) did not provide any missing data (mean and SD for single item, subscale, or total FMS scores) and therefore results for meta-analyses were not available. However, these studies reported sufficient descriptive and analytical results to be included in this review.

Meta-analyses

Data were extracted for meta-analyses (KW) and checked for accuracy (CL). Studies that provided the number of participants, measures of baseline and post-test values (means and SD or SE) (Deeks & Higgins, 2010) for total FMS proficiency (total FMS score), subscales or single motor skill items were included. Post-intervention values were taken for meta-analyses. We chose the INT that focused on interventions taking place in the childcare or kindergarten setting if more than one INT was included (Deli et al., 2006; Humeric, 2011; Yin et al., 2012). Outcome data of total FMS proficiency and subscales were pooled after conversion to the most familiar and most used instrument (TGMD-2 [Test of Gross Motor Development—2nd edition]) to enhance interpretability of meta-analyses results (Thorlund et al., 2011). Because of scarce subgroup data (e.g., for gender (Iivonen et al., 2011; Zask et al., 2012), motivational climates (Robinson & Goodway, 2009)), these groups were combined for the meta-analysis of total FMS scores (Higgins & Green, 2011). To verify the effectiveness of FMS intervention programs in childcare and kindergarten settings, we computed between-group standardized mean differences as $SMD_{between}$ = (mean post-test value in INT group – mean post-test value in CON group)/pooled variance to report the average treatment effect (Deeks & Higgins, 2010). We combined $SMD_{between}$ according to random-effect analyses to obtain an overall SMD for included studies that were further weighted for magnitude of the respective SE. $SMD_{between}$ were adjusted for the respective sample size (Hedges' adjusted *g*) (Deeks & Higgins, 2010) and expressed based on Cohen's (1988) categorizing values for SMD_{within}/$SMD_{between}$ of < 0.5 as small, 0.5–0.79 as medium, and ≥ 0.80 as large effects (Cohen, 1988). Studies that provided insufficient data to be included in meta-analyses, but fulfilled our eligibility criteria, were kept in the review (Deli et al., 2006; Kelly et al., 1989; Wang, 2004; Weiß et al., 2004).

Investigation of heterogeneity, subgroup and exploratory analyses

Heterogeneity between studies was assessed using I^2 statistics. To explain expected heterogeneity among study results, we defined a set of two a priori hypotheses on which sensitivity analyses of subgroups were performed. First, we hypothesized that, based on social-cognitive theory (Bandura, 1989) and the stages of behavioral change (Prochaska & Velicer, 1997), an intervention of 6–8 months is the minimum amount of time needed for a sustainable change in behavior, not so much by the children themselves, but by the childcare and kindergarten professionals and the parents who direct the behavior of children at this young age. Second, we hypothesized that the results of trials would be influenced by their methodological quality. Only for this purpose, we compared 'high quality' trials based on our quality rating with 'moderate' and 'low quality' studies, respectively (ESM Table S4), using all studies that reported total FMS, OCS, or LMS scores. For three studies that reported both OCS and LMS scores but no total FMS score (Goodway et al., 2003; Goodway & Branta, 2003; Valentini, 1999), the subscale scores were combined (Casella & Berger, 2002) to calculate the total FMS score; the variance was then determined by using a correlation between OCS and LMS of 1.0 as a conservative approach (Cools et al., 2009). For both subgroup analyses (e.g., methodological quality, duration of the intervention) we calculated weighted mean $SMD_{between}$ for the subgroups to test our hypotheses using Review Manager 5.3 (Copenhagen: The Nordic Cochrane Center, The Cochrane Collaboration, 2014). Due to the heterogeneity of FMS assessment tools used in studies, we defined a further posteriori hypothesis that test results would not vary according to the test battery used. As the majority of studies used one specific test (TGMD or TGMD-2), we compared those studies that used either version of this test battery versus those that used another test.

Further exploratory analyses were done to identify interventions that were more effective than others. These included the evaluation of differences in effect sizes according to target groups (e.g., focusing on risk populations for developmental delays rather than taking a population approach, differences in gender), the setting (e.g., kindergarten or childcare) or intervention characteristics (e.g., the use of a theoretical framework on which the intervention was built on, the integration of expert teachers versus the usual childcare or kindergarten teacher, parental involvement).

Certainty in treatment estimates

We used the GRADE approach to categorize certainty in effect estimates for all reported outcomes as high, moderate, low, or very low (Guyatt, G. et al., 2011). Based on this approach, RCTs start as high certainty but can be rated down because of risk of bias, inconsistency, indirectness, imprecision, and publication bias. CTs start as low certainty, but can be upgraded based on large magnitude effects, dose-response results or confounders that likely minimized the effect (Guyatt, G. H., Oxman, A. D., Sultan, S. et al., 2011). The results are presented in GRADE evidence profiles (Guyatt et al., 2013) using GRADEproGDT (http://www.guidelinedevelopment.org/).

Results

Study characteristics

Overall, we identified 17,566 unique records, of which we assessed 41 articles for eligibility (Fig. 1). After reviewing the full texts, 30 articles were eligible including 6126 children with an age range of 3.3–5.5 years.

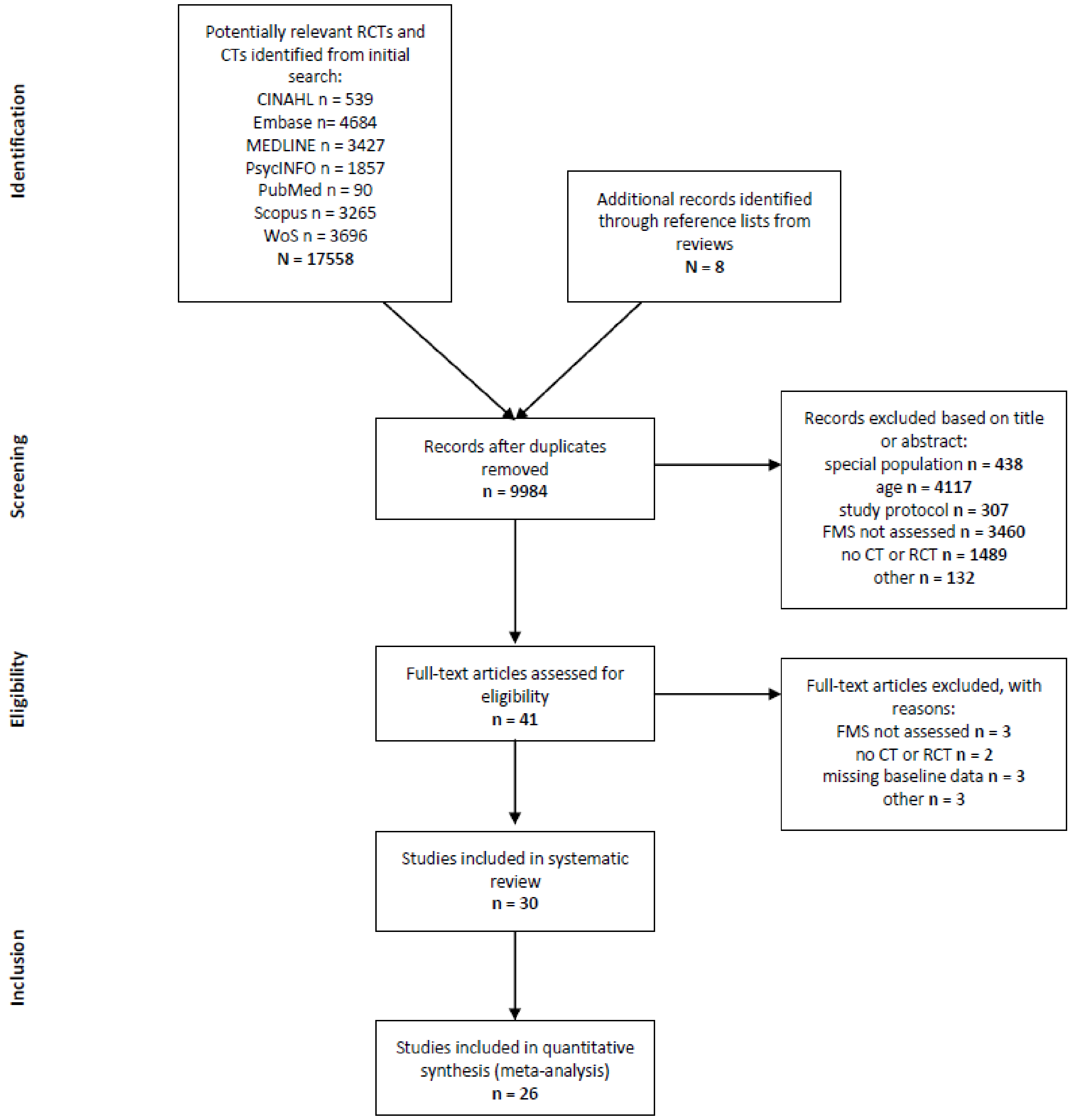


Figure 1 Study flow chart (Moher et al., 2009). CT= controlled trial, FMS = fundamental movement skills, RCT = randomized controlled trial, WoS = Web of Science

All included trials are shown in Table 1. Twelve of the 30 studies were carried out in the US (Alhassan et al., 2012; Bellows et al., 2013; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Humeric, 2011; Ignico, 1991; Kelly et al., 1989; Robinson & Goodway, 2009; Valentini, 1999;

Vidoni et al., 2014; Yin et al., 2012), 12 in European countries (Bonvin et al., 2013; Deli et al., 2006; Derri et al., 2001; Donath et al., 2015; Iivonen et al., 2011; Krombholz, 2012; Puder et al., 2011; Reilly et al., 2006; Roth et al., 2015; Tsapakidou et al., 2014; Venetsanou & Kambas, 2004; Weiß et al., 2004), and the remainder elsewhere (Iran (Hashemi et al., 2015), Australia (Hardy et al., 2010; Jones, Riethmuller et al., 2011; Piek et al., 2013; Zask et al., 2012), and Taiwan (Wang, 2004)). There were 15 RCTs (Alhassan et al., 2012; Bellows et al., 2013; Bonvin et al., 2013; Derri et al., 2001; Donath et al., 2015; Hardy et al., 2010; Humeric, 2011; Jones, Riethmuller et al., 2011; Piek et al., 2013; Puder et al., 2011; Reilly et al., 2006; Robinson & Goodway, 2009; Roth et al., 2015; Vidoni et al., 2014; Zask et al., 2012), including 14 cluster RCTs (Alhassan et al., 2012; Bellows et al., 2013; Bonvin et al., 2013; Donath et al., 2015; Hardy et al., 2010; Humeric, 2011; Jones, Riethmuller et al., 2011; Piek et al., 2013; Puder et al., 2011; Reilly et al., 2006; Robinson & Goodway, 2009; Roth et al., 2015; Vidoni et al., 2014; Zask et al., 2012), and 15 CTs (Deli et al., 2006; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Hashemi et al., 2015; Ignico, 1991; Iivonen et al., 2011; Kelly et al., 1989; Krombholz, 2012; Tsapakidou et al., 2014; Valentini, 1999; Venetsanou & Kambas, 2004; Wang, 2004; Weiß et al., 2004; Yin et al., 2012) including eight cluster CT studies (Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Ignico, 1991; Iivonen et al., 2011; Kelly et al., 1989; Krombholz, 2012; Yin et al., 2012). The duration of the interventions ranged from 6 weeks to 20 months. Ten studies (Alhassan et al., 2012; Bonvin et al., 2013; Iivonen et al., 2011; Krombholz, 2012; Piek et al., 2013; Puder et al., 2011; Reilly et al., 2006; Roth et al., 2015; Weiß et al., 2004; Zask et al., 2012) lasted ≥ 6 months and seven studies (Humeric, 2011; Iivonen et al., 2011; Piek et al., 2013; Reilly et al., 2006; Robinson & Goodway, 2009; Roth et al., 2015; Valentini, 1999) had a follow-up of 9 weeks to 18 months after the end of the intervention period. The frequency of FMS intervention sessions given per week varied between once per week to daily. Five studies (Alhassan et al., 2012; Ignico, 1991; Roth et al., 2015; Vidoni et al., 2014; Yin et al., 2012) offered an FMS intervention every day, 22 studies (Bellows et al., 2013; Deli et al., 2006; Derri et al., 2001; Donath et al., 2015; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Hashemi et al., 2015; Humeric, 2011; Iivonen et al., 2011; Jones, Riethmuller et al., 2011; Kelly et al., 1989; Krombholz, 2012; Piek et al., 2013; Puder et al., 2011; Reilly et al., 2006; Robinson & Goodway, 2009; Tsapakidou et al., 2014; Valentini, 1999; Venetsanou & Kambas, 2004; Wang, 2004; Zask et al., 2012) two to four times per week, one study (Weiß et al., 2004) once a week and two studies (Bonvin et al., 2013; Hardy et al., 2010) did not specify the frequency.

Table 1. Intervention characteristics of included studies

Study	Design	Target population	Setting; participants (mean age ± SD years)	Assessment[a]	Intervention program	Overview results[b]
Alhassan et al. (2012) United States	Cluster-randomized controlled trial; INT and CON: 4 classrooms from 2 preschool centers each	Ethnic minority preschoolers	Preschool centers; INT: n = 43 (4.5 ± 0.6), CON: n = 28 (4.1 ± 0.6)	**FMS:** TGMD-2 (LMS) **PA:** Accelerometer **BC:** Height, weight, BMI (z-scores) **Data collection**: 0, 6 months	**Duration**: 6 months **INT**: 30 minutes structured PA lessons 5x/week; Lessons focusing on one of the skills of the TGMD-2 LMS; Training sessions for teachers (totally 8 hours) **CON:** 30 minutes unstructured free play time 5x/week; Training sessions for teachers (totally 2 hours)	**FMS**: leaping INT > CON; remaining tests INT ≈ CON **PA:** sedentary INT < CON **BC**: INT ≈ CON
Bellows et al. (2013) United States	Cluster-randomized controlled trial; INT and CON: 4 Head Start centers each	Preschool-aged children	Head Start centers; INT: n = 132 (4.4 ± 0.6), CON: n = 131 (4.3 ± 0.6)	**FMS:** PDMS-2 (totFMS, OCS, LMS) **PA:** pedometers **BC:** height, weight, BMI (z-scores) **Data collection:** 0, 18 weeks	**Duration:** 18 weeks **INT:** 15-20 minutes structured PA lessons 4x/week; Lessons including multiple activities focusing on one or a group of skills from one of the three gross motor skill categories (Balance, LMS, OCS) by introducing fictive characters promoting motor skills and food; Home material; Training sessions for teachers; Additionally, those characters were also part of another nutrition-based study called "food friends", which took place in the same time **CON:** nutrition-based "food friends" study	**FMS:** INT > CON **PA:** INT ≈ CON **BC:** INT ≈ CON
Bonvin et al. (2013) Switzerland	Cluster-randomized controlled trial; INT and CON: 29 childcare centers each	Young children aged 2-4 years	Childcare centers; INT: n = 313 (3.4 ± 0.6), CON: n = 335 (3.3 ± 0.6)	**FMS:** adapted ZNA (totFMS) **PA:** accelerometer **BC:** height, weight, BMI **Data collection:** 0, 9 months	**Duration:** 9 months **INT:** 5 workshops for educators providing education in PA; Promoting PA to parents by childcare educators; Flyers; Documentation and support at childcare through coordinator; Focus groups every 2 months; Financial support for childcare centers to design activity friendly spaces **CON:** regular preschool program	**FMS:** INT ≈ CON **PA:** INT ≈ CON **BC:** INT ≈ CON
Deli et al. (2006)[c] Greece	Controlled trial; INT1, INT2 and CON: 1 class each, created out of the study participants	Kindergarten children	Preschool center; INT1: n = 25 (5.4 ± 0.5), INT2: n = 25 (5.5 ± 0.3), CON: n = 25 (5.4 ± 0.6)	**FMS:** TGMD **PA:** none **BC:** none **Data collection:** 0, 10 weeks	**Duration:** 10 weeks **INT1:** 35 minutes structured movement lessons 2x/week; Lessons in week 1-4 including exercises for body/space awareness, lessons in week 5-10 including locomotor skills **INT2:** 35 minutes structured music and movement lessons 2x/week focusing on percussion, reaction and creative movements; Lessons in week 1-4 including exercises for body/space awareness and for determining personal rhythm, lessons in week 5-7 focusing on movement synchronization to external rhythms, and lessons in week 8-10 combining rhythm and fundamental locomotor skills	**FMS:** INT > CON **PA:** none **BC:** none

					CON: free-play activities	

Table 1 continued

Study	Design	Target population	Setting; participants (mean age ± SD years)	Assessment[a]	Intervention program	Overview results[b]
Derri et al. (2001) Greece	Randomized controlled trial; INT and CON: 1 group each, created out of the study participants	Preschool children	No information about setting; INT: n = 35 (*N/A*), CON: n = 33 (*N/A*), INT and CON: 5.4 ± 0.6	**FMS:** TGMD (LMS) **PA:** none **BC:** none **Data collection:** 0, 10 weeks	**Duration:** 10 weeks **INT:** 35-40 minutes structured music and movement lessons 2x/week; lessons including body/space awareness, reaction, percussion movements and improvisation skills, and combining rhythm and fundamental locomotor skills **CON:** 30-40 minutes free-play activities 2x/week	**FMS:** galloping, leaping, horizontal jump, skipping INT > CON; remaining tests INT ≈ CON **PA:** none **BC:** none
Donath et al. (2015)[c] Switzerland	Cluster-randomized controlled trial; INT and CON: 3 kindergartens each	Kindergarten children	Kindergartens; INT: n = 22 (4.4 ± 1.0), CON: n = 19 (4.4 ± 1.2)	**FMS:** TGMD-2 (OCS) **PA:** none **BC:** height, weight, BMI **Data collection:** 0, 6 weeks	**Duration:** 6 weeks **INT:** 30 minutes structured training sessions 2x/week; lessons including object control exercises **CON:** instructed and supervised training 2x/week for playing activities by inexperienced instructor; No changes of daily physical and sportive activities	**FMS:** total sum score, stationary dribbling INT > CON; remaining tests INT ≈ CON **PA:** none **BC:** INT ≈ CON
Goodway & Branta (2003) United States	Clustered controlled trial; INT and CON: 2 preschool classes each	Disadvantaged preschool children	Preschool classes; INT: n = 31 (4.7 ± 0.3), CON: n = 28 (4.7 ± 0.3)	**FMS:** TGMD (OCS, LMS) **PA:** none **BC:** none **Data collection:** 0, 13 weeks	**Duration:** 12 weeks **INT:** 45 minutes instructional lessons 2x/week; lessons including sustained activity (10 minutes), skill instruction (3x10 minutes), and emphasizing key components of those skills (3 minutes) **CON:** typical preschool program including free play time	**FMS:** INT > CON **PA:** none **BC:** none
Goodway et al. (2003) United States	Cluster-controlled trial; INT and CON: 2 Pre-Kindergarten classes each	Pre-Kindergarten children at risk for DD	Pre-Kindergarten: INT: n = 33 (4.9 ± 0.4) CON: n = 30 (5.0 ± 0.4)	**FMS:** TGMD (OSC, LMS) **PA:** none **BC:** none **Data collection:** 0, 9 weeks	**Duration:** 9 weeks **INT:** 35 minutes instructional sessions 2x/week; three 10 minute periods of skill instruction, using developmentally and instructionally appropriate practice **CON:** typical Pre-Kindergarten curriculum	**FMS:** INT > CON **PA:** none **BC:** none
Hamilton et al. (1999) United States	Clustered controlled trial; INT: 3 preschool classes, CON: 2 preschool classes	Preschool children at risk for DD	Preschool classes; INT: n = 15 (3.9 ± 0.2), CON: n = 12 (4.0 ± 0.3)	**FMS:** TGMD (OCS) **PA:** none **BC:** none **Data collection:** 0, 8 weeks	**Duration:** 8 weeks **INT:** 45 minutes parent-assisted instructional lessons 2x/week; lessons including a minimum of two of the five object control skills, presented by parents at the center; parent instruction prior to each lesson (15 minutes); Parent orientation meetings previous to study begin (2x45 minutes) **CON:** regular activity program including movement songs and activities with parents, and opportunities for movement exploration 2x/week for 45 minutes	**FMS:** INT > CON **PA:** none **BC:** none

Table 1 continued

Study	Design	Target population	Setting; participants (mean age ± SD years)	Assessment[a]	Intervention program	Overview results[b]
Hardy et al. (2010) Australia	Cluster-randomized controlled trial; INT: 15 preschools; CON: 14 preschools	Preschool-aged children	Preschools and long day care centers; INT: n = 263 (4.4 ± 0.5), CON: n = 167 (4.5 ± 0.3)	**FMS:** TGMD-2 (totFMS, OCS, LMS) **PA:** none **BC:** none **Data collection:** 0, 20 weeks	**Duration:** 20 weeks **INT:** one-day professional workshop for preschool staff (incorporating healthy eating and PA into education program; structural and organizational changes in preschools); Resources for preschools (manual; small grant for purchasing activity equipment or support staff to attend training); Contact with health promotion professionals **CON:** Preschools provided with written information on sun and road safety	**FMS:** INT ≈ CON **PA:** none **BC:** none
Hashemi et al. (2015) Iran	Controlled trial; INT and CON: no information about allocation	Preschool girls from non-affluent families without post graduated education	Kindergartens; INT: n = 30 (5.1 ± 0.0), CON: n = 30 (5.0 ± 0.1)	**FMS:** TGMD-2 (OCS) **PA:** none **BC:** height, weight **Data collection:** 0, 6 weeks	**Duration:** 6 weeks **INT:** 45 minutes structured lessons 3x/week; Lessons including warm-up, selected games (i.e. ball dodging), and cool-down **CON:** regular daily activity	**FMS:** INT > CON **PA:** none **BC:** none
Hurmeric (2011) United States	Cluster-randomized controlled trial; INT1 and INT2: 3 mixed classes from 1 center; CON: 1 group from another center	Preschool children	Head Start centers; INT1: n = 22 (4.0 ± 0.5), INT2: n = 25 (4.1 ± 0.5), CON: n = 25 (4.0 ± 0.6)	**FMS:** TGMD-2 (OCS) **PA:** none **BC:** height, weight, BMI, grip strength, body fat **Data collection:** 0, 8 weeks; Follow-up at 12 weeks	**Duration:** 8 weeks **INT1:** 30 minutes structured movement lessons 2x/week; lessons including warm-up, instructions for two object control skills (2x12 minutes), and closure activities **INT2:** same intervention as INT1; additional 10-15 minutes movement lesson at home conducted by primary caregiver with lesson plan, instructions and standardized equipment provided; workshop prior to intervention **CON:** regular Head Start curriculum, including outdoor and large muscle activities	**FMS:** INT1 ≈ INT2 > CON **PA:** none **BC:** none
Ignico (1991) United States	Clustered controlled trial; INT and CON: 1 kindergarten class each	Kindergarten children	Elementary school; INT: n = 15 (*N/A*), CON: n = 15 (*N/A*)	**FMS:** TGMD (totFMS) **PA:** none **BC:** none **Data collection:** 0, 10 weeks	**Duration:** 10 weeks **INT:** 28 minutes structured training sessions 5x/week; lessons including three stations **CON:** regular activities, including 20-25 minutes free play time	**FMS:** INT > CON **PA:** none **BC:** none
Iivonen et al. (2011) Finland	Clustered controlled trial; INT and CON: 2 classes from 2 preschools each; distinction of sex	Preschool children	Preschools; INT: n = 39 (*N/A*), CON: n = 35 (*N/A*), INT and CON: 4.6 ± 0.1	**FMS:** adapted APM Inventory (OCS) **PA:** none **BC:** none **Data collection:** 0, 4, 8 months, follow-up at 11 months	**Duration:** 8 months **INT:** 45 minutes physical education lessons 2x/week; lessons according to the Physical Education Curriculum (PEC) of the Early Steps Project (Zachopoulou et al., 2010) **CON:** 60 minutes unstructured physical education lesson 1x/week	**FMS:** INT ≈ CON **PA:** none **BC:** none

Table 1 continued

Study	Design	Target population	Setting; participants (mean age ± SD years)	Assessment[a]	Intervention program	Overview results[b]
Jones et al. (2011) Australia	Cluster-randomized controlled trial; INT and CON: 1 class from 1 childcare center each	Preschool children	Childcare centers; INT: n = 52 (*N/A*), CON: n = 45 (*N/A*), INT and CON: 4.1 ± *N/A*	**FMS:** TGMD-2 (totFMS) **PA:** accelerometer **BC:** height, weight, BMI **Data collection:** 0, 20 weeks	**Duration:** 20 weeks **INT:** 20 minutes structured PA lessons 3x/week; lessons focusing on one MC each week; theoretical and practical workshops (4x30 minutes) for the staff; specific equipment provided to childcare **CON:** usual program, including designated time outside for free play	**FMS:** INT > CON **PA:** INT > CON **BC:** none
Kelly et al. (1989) United States	Clustered controlled trial; INT: 2 groups from 1 preschool; CON: 1 group from another preschool	Preschool children	Motor Development Clinic (INT), Preschool (CON); INT: n = 21 (4.4 ± 0.7), CON: n = 26 (4.2 ± 0.7)	**FMS:** MEAP-Test **PA:** none **BC:** none **Data collection:** 0, 6, 12 weeks	**Duration:** 12 weeks **INT:** 50 minutes physical education instruction 2x/week; lessons including free play (5 minutes), introductory activities (8 minutes), instructional activities (30 minutes) and summary activities (7 minutes) **CON:** daily periods of supervised free play on well-equipped playground; no formal instruction in physical education	**FMS:** INT ≈ CON **PA:** none **BC:** none
Krombholz (2012)[c] Germany	Clustered controlled trial; INT and CON: 11 childcare centers each	Preschool children	Childcare centers; INT: n = 211 (4.6 ± 0.6), CON: n = 217 (4.5 ± 0.7)	**FMS:** MoTB 3-7 (totFMS) **PA:** none **BC:** height, weight, BMI, body fat **Data collection:** 0, 11, 20 months	**Duration:** 20 months **INT:** 45 minutes physical education session 1x/week; additional 20 minutes PA on the other days; lessons contents free to choose; raise awareness and train competency of educators **CON:** usual curriculum, including 45 minutes physical education session 1x/week	**FMS:** INT ≈ CON **PA:** none **BC:** INT ≈ CON
Piek et al. (2013)[c] Australia	Cluster-randomized controlled trial; INT and CON: 6 schools each	Young children aged 4-6 years from low socio-economic area	Primary schools; INT: n = 254 (*N/A*), CON: n = 196 (*N/A*), INT and CON: 5.4 ± 0.3	**FMS:** BOT-2SF, MABC-2 (totFMS) **PA:** none **BC:** height, weight, BMI (z-score), waist circumference **Data collection:** 0, 6 months; Follow-up at 18 months	**Duration:** 6 months **INT:** 30 minutes PA lessons 4x/week; lessons including different modules of the Animal Fun Program (body management, locomotion, object control, …); 1-day training course for teachers prior to intervention **CON:** normal curriculum	**FMS:** INT ≈ CON **PA:** none **BC:** none
Puder et al. (2011) Switzerland	Cluster-randomized controlled trial; INT and CON: 20 preschool classes each from a total of 30 preschools in two different country regions	Preschool children from an area with high proportion of migrants	Preschool; INT: n = 342 (5.2 ± 0.6), CON: n = 310 (5.2 ± 0.6)	**FMS:** Shuttle run (20m), obstacle course, balance beam & platform **PA:** accelerometer **BC:** height, weight, BMI, body fat, waist circumference **Data collection:** 0, 9 months	**Duration:** 9 months **INT:** 45 minutes PA lessons 4x/week; lessons including mainly aerobic exercises in/around the school and in the gym; home material; nutritional intervention **CON:** regular school curriculum, including 45 minutes PA in the gym 1x/week in both regions, and another 45 minutes rhythmic lesson in the other region	**FMS:** shuttle run, obstacle course INT > CON; remaining tests INT ≈ CON **PA:** INT > CON **BC:** body fat, waist circumference INT < CON; remaining tests INT ≈ CON

Table 1 continued

Study	Design	Target population	Setting; participants (mean age ± SD years)	Assessment[a]	Intervention program	Overview results[b]
Reilly et al. (2006) Scotland	Cluster-randomized controlled trial; INT and CON: 18 nurseries each	Young children	Nurseries; INT: n = 268 (4.2 ± 0.3), CON: n = 277 (4.1 ± 0.3)	**FMS:** MABC (totFMS) **PA:** accelerometer **BC:** height, weight, BMI (SD score) **Data collection:** 0, 6 months; Follow-up at 12 months	**Duration:** 24 weeks **INT:** 30 minutes PA lessons 3x/week; lessons intending to increase PA levels of children and meet the requirements of the "physical development and movement" component of the nursery curriculum of Scotland; Training sessions for nurses (3x); resource pack of materials for home based intervention (health education leaflets); posters displayed at nurseries for six weeks **CON:** usual curriculum, with the head teachers agreeing not to enhance physical development and movement curriculum	**FMS:** INT > CON **PA:** moderate-vigorous INT > CON; remaining measures INT ≈ CON **BC:** INT ≈ CON
Robinson & Goodway (2009) United States	Cluster-controlled trial; INT: 1 Head Start center; CON: 1 Head Start center	Preschool children at risk for DD	Head Start centers: INT1/2: n = 77 (3.9 ± 0.6) CON: n = 40 (4.0 ± 0.4)	**FMS:** TGMD-2 (OCS) **PA:** none **BC:** none **Data collection:** 0, 9 weeks; Follow-up at 9 weeks	**Duration:** 9 weeks **INT:** 30 minutes motor skill intervention 2x/week "Low autonomy (INT1) or "mastery motivational climate" (INT2); warm-up activity (2-3 minutes), motor skill instruction for OC skills (24 minutes), closure activity (2-3 minutes), typical Head Start curriculum;+30 minutes unstructured recess 2x/week **CON:** typical Head Start curriculum; 30 minutes unstructured recess 2x/week	**FMS:** INT(INT1/2) > CON **PA:** none **BC:** none
Roth et al. (2015) Germany	Cluster-randomized controlled trial; INT: 21 preschools; CON: 20 preschools	Preschool children	Preschools; INT: n = 368 (4.7 ± 0.6), CON: n = 341 (4.7 ± 0.5)	**FMS:** Ssingle items (obstacle course, standing long jump, balancing on one foot, jumping to and fro sideways) – composite z-score (totFMS) **PA:** accelerometer **BC:** height, weight, BMI (z-score), blood pressure, body fat **Data collection:** 0, 6, 11 months; follow-up at 13-15 months	**Duration:** 11 months **INT:** 30 minutes PA lessons 5x/week; lessons including exercises to enhance coordinative skills and perception; manual, collection of games, and exercises for preschools; PA homework cards 1x or 2x/week; letters comprising games/exercises for holidays **CON:** routine schedule, including common daily activity and weekly PA class	**FMS:** INT > CON, one-leg stance, standing long jump, lateral jump INT > CON; obstacle course INT ≈ CON **PA:** INT ≈ CON **BC:** body fat INT < CON; remaining tests INT ≈ CON
Tsapakidou et al. (2014) Greece	Controlled trial: INT and CON: 3 kindergartens together	Children aged 3.5-5 years	Nursery schools; INT: n = 49 (*N/A*), CON: n = 49 (*N/A*), INT & CON: (3.5 – 5)	**FMS:** TGMD-2 (LMS) **PA:** none **BC:** none **Data collection:** 0, 2 months	**Duration:** 2 months **INT:** 30-40 minutes physical education lessons 2x/week; lessons including exercises to raise body awareness, rhythm, coordinative skills and creativity to develop basic motor skills **CON:** daily schedule	**FMS:** INT > CON **PA:** none **BC:** none

Table 1 continued

Study	Design	Target population	Setting; participants (mean age ± SD years)	Assessment[a]	Intervention program	Overview results[b]
Valentini (1999) United States	Controlled trial; INT and CON: 1 early education center together	Low motor skill functioning children	Early education center; INT: n = 38 (5.1 ± 0.3), CON: n = 29 (5.3 ± 0.5)	**FMS:** TGMD (OCS, LMS) **PA:** none **BC:** none **Data collection:** 0, 12 weeks; follow-up at 9 months	**Duration:** 12 weeks **INT:** 35 minutes motor skill lessons 2x/week; lessons including introduction, motor skill instruction and practice (30 minutes), and closure, according to TARGET structure (Ames, 1992) **CON:** N/A	**FMS:** LMS INT > CON, OCS INT ≈ CON **PA:** none **BC:** none
Venetsanou & Kambas (2004) Greece	Controlled trial; no information about allocation	Preschool children	Kindergarten; INT: n = 28 (*N/A*) CON: n = 38 (*N/A*), INT and CON: 5.0 ± 0.5	**FMS:** MOT 4-6 (totFMS) **PA:** none **BC:** none **Data collection:** 0, 20 weeks	**Duration:** 20 weeks **INT:** 45 minutes musical movement lessons 2x/week; lessons including percussive movements and rhythmical locomotion (i.e. singing games, playing percussion instruments) **CON:** regular kindergarten curriculum activities	**FMS:** INT > CON **PA:** none **BC:** none
Vidoni et al. (2014) United States	Cluster-randomized controlled trial; INT and CON: 1 class of the same day-care center each	Preschool children	Daycare center INT: n = 18 (*N/A*), CON: n = 15 (*N/A*), INT and CON: 4.5 ± *N/A*	**FMS:** BOT-2SF (totFMS) **PA:** none **BC:** none **Data collection:** 0, 11 weeks	**Duration:** 11 weeks **INT:** 30 minutes structured PA program 5x/week; lessons including circuit training and exercises based on the MAZE approach (Meyer, 2012) **CON:** regular day-care center schedule, including 30 minutes unstructured PA 5x/week	**FMS:** INT > CON **PA:** none **BC:** none
Wang (2004) Taiwan	Controlled trial; INT and CON: 1 group of the same preschool each	Preschool children	Preschool INT: n = 30 (*N/A*), CON: n = 30 (*N/A*), INT and CON: (3-5)	**FMS:** PDMS-2 **PA:** none **BC:** none **Data collection:** 0, 6 weeks	**Duration:** 6 weeks **INT:** 30 minutes creative movement lessons 2x/week; lessons including exploring, developing and creating different movements in relation to dancing **CON:** unstructured free play	**FMS:** LMS INT > CON; remaining tests INT ≈ CON **PA:** none **BC:** none
Weiss et al. (2004) Germany	Controlled trial; 1 group of the same kindergarten each	Kindergarten children	Kindergarten INT: n = 24 (4.7 ± *N/A*), CON: n = 22 (4.9 ± *N/A*),	**FMS:** MOT 4-6 **PA:** none **BC:** height, weight, BMI **Data collection:** 0, 6 months	**Duration:** 6 months **INT:** 60 minutes back training lessons 1x/week; lessons including a variety of games in combination with different material **CON:** usual kindergarten schedule including regular PA lessons	**FMS:** INT > CON **PA:** none **BC:** none

Table 1 continued

Study	Design	Target population	Setting; participants (mean age ± SD years)	Assessment[a]	Intervention program	Overview results[b]
Yin et al. (2012) United States	Clustered Controlled trial; INT1: 14 classes in 2 centers; INT2: 5 classes in 1 center; CON: 6 classes in 1 center	Preschool aged children	Head Start centers; INT1: n = 179 (4.1 ± 0.6), INT2: n = 80 (4.2 ± 0.5), CON: n = 97 (4.1 ± 0.5)	**FMS:** LAP-3 (totFMS) **PA:** pedometer **BC:** height, weight, BMI (z-score) **Data collection:** 0, 18 weeks; additional 3 mid-study tests	**Duration:** 18 weeks **INT1:** 30-45 minutes structured and unstructured outdoor lessons 5x/week; lessons including gross motor skills teaching and dance instruction; supplemental classroom activities; healthy eating promotion **INT2:** same intervention as INT1; additional take-home activities, parent obesity education and family support monitoring for healthy eating and PA **CON:** regular schedule, including unstructured free play on the playground 5x/week	**FMS:** INT1 > CON, INT2 > CON **PA:** INT1 > CON, INT2 > CON **BC:** BMI INT1 ≈ CON, INT2 < CON
Zask et al. (2012) Australia	Cluster-randomized controlled trial; INT: 18 preschools; CON: 13 preschools	Children aged 3-6 years	Preschools; INT: n = 273 (*N/A*) CON: n = 142 (*N/A*) INT and CON: 4.6 ± 0.6	**FMS:** TGMD-2 (totFMS, LMS) **PA:** none **BC:** height, weight, BMI (z-score), waist circumference **Data collection:** 0, 10 months	**Duration:** 10 months **INT:** 25-30 minutes structured FMS development lessons 2x/week; lessons including warm-up (5 minutes), games in groups (15-20 minutes), and cool-down (5 minutes); small grant for equipment; playground review to encourage more active behavior; workshops and monthly newsletter for parents; healthy eating intervention **CON:** N/A	**FMS:** INT > CON **PA:** none **BC:** BMI, waist circumference INT < CON

AMP = Alle kouluika¨isten lasten PsykoMotoriset taidot, BC = body composition, BMI = body mass index, BOT-2SF = Bruininks-Oseretsky test of motor proficiency—version 2 Short Form, CON = control group, DD = developmental delay, FMS = fundamental movement skills, INT = intervention group, LAP-3 = Learning Achievement Profile 3rd edition, LMS = locomotor subscale, MABC-2 = Movement assessment battery for children-version 2, MEAP = Michigan Educational Assessment Program, MOT4-6 = Motorik test for 4- to 6-year-old children, MoTB3-7 = motor test battery, N/A = not available, OCS = object control subscale, PA = physical activity, PDMS-2 = Peabody Development Motor Scale—2nd edition, SD = standard deviation, TGMD-2 = Test of Gross Motor Development—2nd edition, totFMS = total fundamental movement skill score, ZNA = Zurich Neuromotor Assessment

a Electronic Supplementary Material Table S2 gives an overview of all used FMS test batteries within included studies

b For detailed information see Electronic Supplementary Material Table S5; results depicted are only between groups post-intervention provided from studies; for </>, there is a significant difference; for≈, there is no significant difference

c Number of participants and mean age ± SD in years only available for post-test period

Fifteen studies (Alhassan et al., 2012; Bellows et al., 2013; Donath et al., 2015; Goodway et al., 2003; Humeric, 2011; Ignico, 1991; Jones, Riethmuller et al., 2011; Krombholz, 2012; Piek et al., 2013; Reilly et al., 2006; Robinson & Goodway, 2009; Roth et al., 2015; Vidoni et al., 2014; Wang, 2004; Zask et al., 2012) documented single intervention sessions lasting between 15 and 30 min, and 13 studies (Deli et al., 2006; Derri et al., 2001; Goodway & Branta, 2003; Hamilton et al., 1999; Hashemi et al., 2015; Iivonen et al., 2011; Kelly et al., 1989; Puder et al., 2011; Tsapakidou et al., 2014; Valentini, 1999; Venetsanou & Kambas, 2004; Weiß et al., 2004; Yin et al., 2012) between 30 to 65 min. Two studies (Bonvin et al., 2013; Hardy et al., 2010) did not provide any information for duration of a single session. All interventions were carried out in childcare or kindergarten settings (i.e., nursery center, early educational center, Head Start center). All interventions included either structured FMS sessions with additional unstructured time for physical activity in five trials (Hardy et al., 2010; Jones, Riethmuller et al., 2011; Kelly et al., 1989; Yin et al., 2012; Zask et al., 2012) or only unstructured physical activity time but specifically devoted to improve FMS in two studies (Bonvin et al., 2013; Krombholz, 2012). In the structured FMS sessions, the intervention protocols consisted of an overall or specific training of FMS, including object control, locomotor, and balance skill exercises, but also coordinative skills, rhythm with percussions and/or music, body awareness and perception, as well as games and creative movements, and improvisation skills. Unstructured physical activity time comprised defined free outdoor playtime and/or additional playground material to encourage physically active behavior and the development of FMS. Eight studies (Bellows et al., 2013; Bonvin et al., 2013; Hamilton et al., 1999; Humeric, 2011; Puder et al., 2011; Reilly et al., 2006; Roth et al., 2015; Zask et al., 2012) also focused on parental work (homework cards and physical activity home assignments for children with promotion of physical activity and FMS to parents) and nine studies set a focus on training sessions (workshops) for staff, nurses, and educators (Alhassan et al., 2012; Bellows et al., 2013; Bonvin et al., 2013; Hardy et al., 2010; Jones, Riethmuller et al., 2011; Krombholz, 2012; Piek et al., 2013; Reilly et al., 2006; Zask et al., 2012). Four studies (Bellows et al., 2013; Puder et al., 2011; Weiß et al., 2004; Yin et al., 2012) also taught the importance of healthy eating and nutrition to the children. To assess FMS (for a precise description of all tests see ESM Table S2), 16 studies (Alhassan et al., 2012; Deli et al., 2006; Derri et al., 2001; Donath et al., 2015; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Hardy et al., 2010; Hashemi et al., 2015; Humeric, 2011; Ignico, 1991; Jones, Riethmuller et al., 2011; Robinson & Goodway, 2009; Tsapakidou et al., 2014; Valentini, 1999; Zask et al., 2012) used the TGMD—first or second edition, two studies (Piek et al., 2013; Vidoni et al., 2014) used the BOT-2SF (Bruininks-Oseretsky Test of motor proficiency—Version 2 Short Form), two (Venetsanou & Kambas, 2004; Weiß et al., 2004) the MOT4-6 (Motorik Test for 4- to 6-year-old children), two (Bellows et al., 2013; Wang, 2004) the PDMS-2 (Peabody Development Motor Scale—2nd edition), and another eight studies (Bonvin et al., 2013; Iivonen et al., 2011; Kelly et al., 1989; Krombholz, 2012; Puder et al., 2011; Reilly et al., 2006; Roth et al., 2015; Yin et al., 2012) used single items or other FMS test batteries.

Risk of bias

Overall, eight out of 30 studies (27%) (Bonvin et al., 2013; Donath et al., 2015; Hardy et al., 2010; Humeric, 2011; Jones, Riethmuller et al., 2011; Puder et al., 2011; Reilly et al., 2006; Roth et al., 2015) were rated to be of high methodological quality (see ESM Table S4). A total of eleven studies (Bellows et al., 2013; Bonvin et al., 2013; Hardy et al., 2010; Krombholz, 2012; Piek et al., 2013; Puder et al., 2011; Reilly et al., 2006; Robinson & Goodway, 2009; Roth et al., 2015; Yin et al., 2012; Zask et al., 2012) had > 100 participants (of those, five studies (Bonvin et al., 2013; Hardy et al., 2010; Puder et al., 2011; Reilly et al., 2006; Roth et al., 2015) were of high quality). Just six studies applied intention-to-treat analyses (Bonvin et al., 2013; Ignico, 1991; Jones, Riethmuller et al., 2011; Puder et al., 2011; Roth et al., 2015; Tsapakidou et al., 2014) but most studies measured the study groups at similar times. Insufficient information was provided to score the adequacy of the randomization procedure in nine studies (Alhassan et al., 2012; Bellows et al., 2013; Bonvin et al., 2013; Derri et al., 2001; Donath et al., 2015; Humeric, 2011; Piek et al., 2013; Vidoni et al., 2014; Zask et al., 2012) (30%), and five studies (Deli et al., 2006; Donath et al., 2015; Kelly et al., 1989; Wang, 2004; Weiß et al., 2004) lacked information on allocation concealment or blinding of assessors at outcome assessment. Most studies reported detailed information regarding the intervention protocol for duration of training and training content (Table 1). However, the curriculum of the CON was not specified beyond usual care in 19 of the 30 studies.

Effects of interventions to improve fundamental movement skills

Findings from 26 out of 30 studies (Alhassan et al., 2012; Bellows et al., 2013; Bonvin et al., 2013; Derri et al., 2001; Donath et al., 2015; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Hardy et al., 2010; Hashemi et al., 2015; Humeric, 2011; Ignico, 1991; Iivonen et al., 2011; Jones, Riethmuller et al., 2011; Krombholz, 2012; Piek et al., 2013; Puder et al., 2011; Reilly et al., 2006; Robinson & Goodway, 2009; Roth et al., 2015; Tsapakidou et al., 2014; Valentini, 1999; Venetsanou & Kambas, 2004; Vidoni et al., 2014; Yin et al., 2012; Zask et al., 2012) were aggregated and included in different meta-analytical calculations (ESM Table S5). For four studies (Deli et al., 2006; Kelly et al., 1989; Wang, 2004; Weiß et al., 2004), results for meta-analytical calculations were not available. Results of those four studies lasting 6 weeks to 6 months included two studies (Deli et al., 2006; Wang, 2004) that reported statistically significant differences for the LMS at post-intervention in favor of the INT, one study (Weiß et al., 2004) found statistically significant differences for overall motor proficiency in favor of the INT, and one study (Kelly et al., 1989) found no significant differences in FMS among groups.

Forest plots and summary results of the meta-analyses for total FMS, OCS, and LMS are described in Fig. 2 and Table 2.

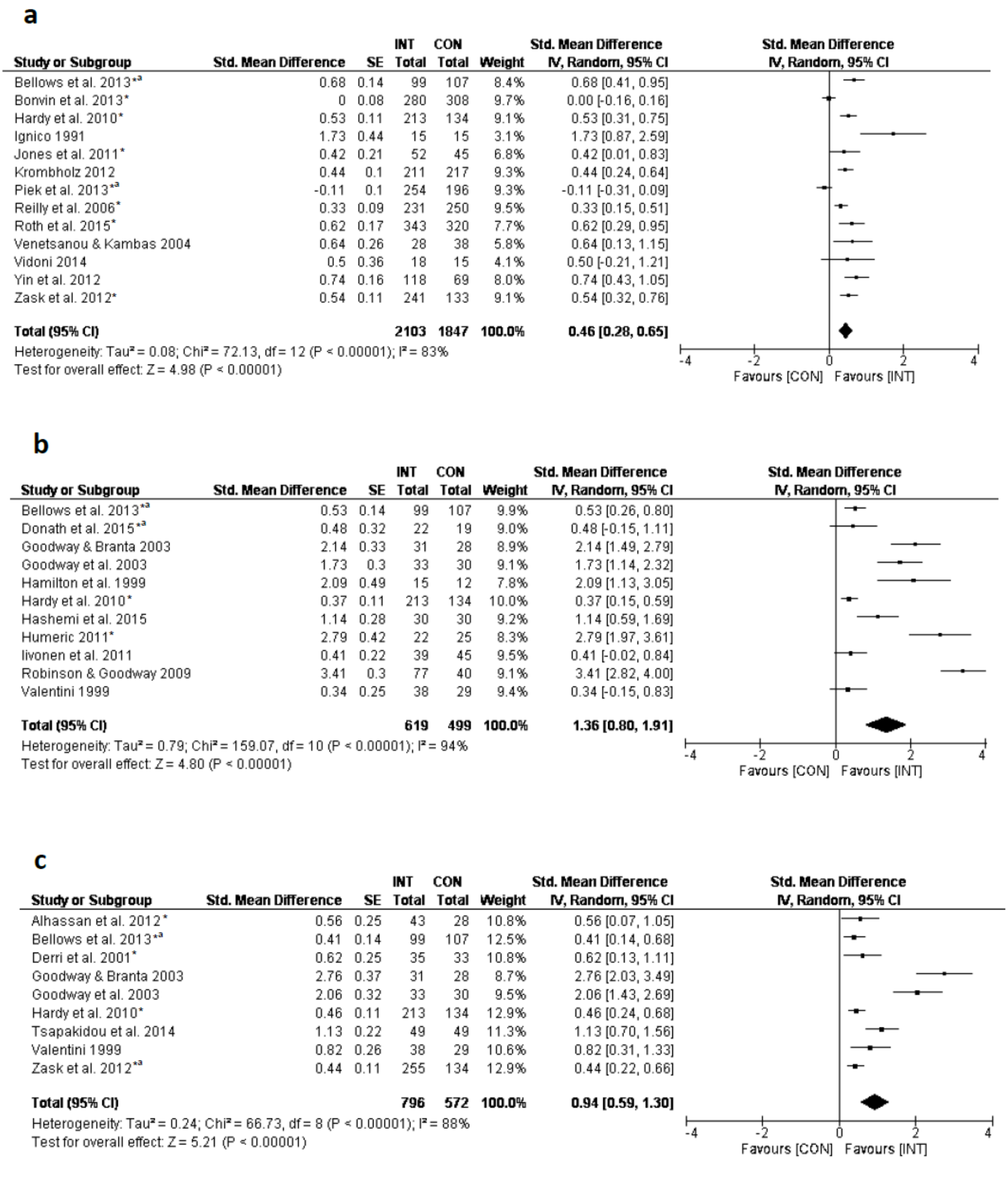


Figure 2 Effects of fundamental movement skills (FMS) interventions on **a)** total FMS score (40-point scale, higher score is better), **b)** object control subscale (OCS; 20-point scale, higher score is better), and **c)** locomotor subscale (LMS; 20-point scale, higher score is better). CI = confidence interval, CON = control group, INT = intervention group, IV = inverse variance, SE = standard error, Std = standardized, *randomized controlled trial, [a] additional information from author

Thirteen (Bellows et al., 2013; Bonvin et al., 2013; Hardy et al., 2010; Ignico, 1991; Jones, Riethmuller et al., 2011; Krombholz, 2012; Piek et al., 2013; Reilly et al., 2006; Roth et al., 2015; Venetsanou & Kambas, 2004; Vidoni et al., 2014; Yin et al., 2012; Zask et al., 2012) out of 26 studies which measured overall motor proficiency (total FMS score) showed small effects of the intervention programs on the INT compared with CON (weighted mean $SMD_{between}$ = 0.46, 95% CI 0.28–0.65; I^2 = 83%, Fig. 2a).

Table 2 GRADE evidence profiles: fundamental movement skills (FMS) enhancing intervention versus usual care

Quality assessment							No. of participants[f]		Absolute effect (95% CI)[f]	Quality	Importance
No. of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	INT	CON			
Overall FMS (follow-up: range 6 weeks to 20 month; assessed with or converted to: TGMD-2; standard score from: 2 to 40)											
16	RCT and CT	Serious[a,b]	Serious[c]	Serious[d]	Not serious	Publication bias[e]	2103	1847	SMD 0.46 higher (0.28 to 0.65 higher)	Very low	Important
OCS (follow-up: range 6 weeks to 8 month; assessed with or converted to: TGMD-2; standard score from: 1 to 20)											
11	RCT and CT	Serious[a,b]	Serious[c]	Serious[d]	Not serious	Publication bias[e]	619	499	SMD 1.36 higher (0.80 to 1.91 higher)	Very low	Important
LMS (follow-up: range 6 weeks to 11 month; assessed with or converted to: TGMD-2; standard score from: 1 to 20)											
10	RCT and CT	Serious[a,b]	Serious[c]	Serious[d]	Not serious	Publication bias[e]	796	572	SMD 0.94 higher (0.59 to 1.30 higher)	Very low	Important

GRADE Working Group grade of evidence

High quality: We are very confident that the true effect lies close to that of the estimate of the effect

Moderate quality: We are moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different

Low quality: Our confidence in the effect is limited: the true effect may be substantially different from the estimate of the effect

Very low quality: We have very little confidence in the effect estimate: the true effect is likely to be substantially different from the estimate of the effect

CI = confidence interval, CON = control group, CT = controlled trial, GRADE = Grading of Recommendations Assessment, Development, and Evaluation System, INT = intervention group, LMS = locomotor subscale, OCS = object control subscale, RCT= randomized controlled trial, SMD = standardized mean difference

[a] Serious because of no clear randomization procedures described

[b] Serious because of selection bias (unclear or inadequate allocation concealment), detection bias (unclear blinding of data analysts), study integrity (unclear compliance with the intervention)

[c] Serious because of statistical heterogeneity (I^2 = 83–88%; p < 0.0001)

[d] Serious because of important differences in implementation across settings

[e] Serious because publication bias possible

[f] 3 and 1 studies for overall FMS and LMS scores, respectively, could not be included in meta-analyses

The subscale-specific analyses revealed large effects of intervention programs on the OCS in 11 (Bellows et al., 2013; Donath et al., 2015; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Hardy et al., 2010; Hashemi et al., 2015; Humeric, 2011; Iivonen et al., 2011; Robinson &

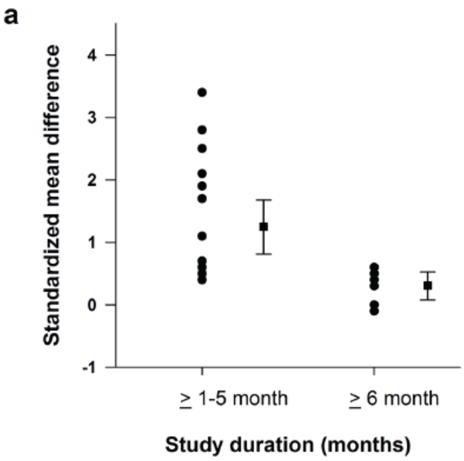
Goodway, 2009; Valentini, 1999) out of 26 studies (weighted mean $SMD_{between}$ = 1.36, 95% CI 0.80–1.91; I^2 = 94%, Fig. 2b) and also large effects in nine studies (Alhassan et al., 2012; Bellows et al., 2013; Derri et al., 2001; Goodway et al., 2003; Goodway & Branta, 2003; Hardy et al., 2010; Tsapakidou et al., 2014; Valentini, 1999; Zask et al., 2012) on the LMS (weighted mean $SMD_{between}$ = 0.94, 95% CI 0.59–1.30; I^2 = 88%, Fig. 2c). Based on GRADE, there was very low certainty of evidence (Table 2) for effect sizes of the total FMS score and both subscale scores including, but not limited to, a high chance of a publication bias (ESM Fig. S1).

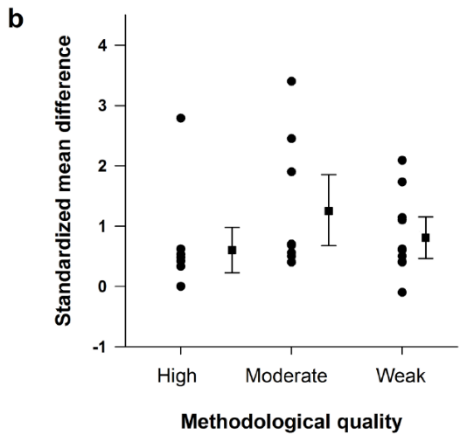
ESM Figs. S2–S4 illustrate forest plots of the intervention effects for single motor skill items integrated in the TGMD-2 scores, and other skills like the standing long jump and balance. Intervention effects were statistically significant in favor of INT for all single items, with effect sizes ranging from low to moderate (0.19–0.83). There was only a small number (i.e., 3–7) of studies in each meta-analysis and a high heterogeneity with I^2 ranging from 73 to 90%, except for the standing long jump that showed an I^2 = 0%. There was no clear picture regarding characteristics of the interventions (frequency, duration), target population (disadvantaged children, age), or setting (childcare, kindergarten) that explained why the effectiveness in total FMS and subscales varied considerably.

Subgroup and Exploratory Analyses

Subgroup Analyses

Figure 3a displays the overall dose–response relationship according to the duration of the interventions. The 17 trials (Bellows et al., 2013; Derri et al., 2001; Donath et al., 2015; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Hardy et al., 2010; Hashemi et al., 2015; Humeric, 2011; Ignico, 1991; Jones, Riethmuller et al., 2011; Robinson & Goodway, 2009; Tsapakidou et al., 2014; Valentini, 1999; Venetsanou & Kambas, 2004; Vidoni et al., 2014; Yin et al., 2012) with a shorter duration (4 weeks to 5 months) showed significantly higher effect sizes on overall FMS compared with those eight studies (Alhassan et al., 2012; Bonvin et al., 2013; Iivonen et al., 2011; Krombholz, 2012; Piek et al., 2013; Reilly et al., 2006; Roth et al., 2015; Zask et al., 2012) with longer duration (> 6 months) (weighted mean $SMD_{between}$ = 1.43, 95% CI 0.49–2.38). Four studies (Deli et al., 2006; Kelly et al., 1989; Wang, 2004; Weiß et al., 2004) did not report their results and, for one study (Puder et al., 2011), data were available only for single items. Figure 3b presents the intervention effects for 25 trials (Alhassan et al., 2012; Bellows et al., 2013; Bonvin et al., 2013; Derri et al., 2001; Donath et al., 2015; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Hardy et al., 2010; Hashemi et al., 2015; Humeric, 2011; Ignico, 1991; Iivonen et al., 2011; Jones, Riethmuller et al., 2011; Krombholz, 2012; Piek et al., 2013; Reilly et al., 2006; Robinson & Goodway, 2009; Roth et al., 2015; Tsapakidou et al., 2014; Valentini, 1999; Venetsanou & Kambas, 2004; Vidoni et al., 2014; Yin et al., 2012; Zask et al., 2012) according to methodological quality. Eight studies (Alhassan et al., 2012; Bellows et al., 2013; Goodway et al., 2003; Goodway & Branta, 2003; Krombholz, 2012; Robinson & Goodway, 2009; Yin et al., 2012; Zask et al., 2012) with 'moderate' (weighted mean $SMD_{between}$ = 1.00, 95% CI -0.09 to 2.10) and ten studies (Derri et al., 2001; Hamilton et al., 1999; Hashemi et al., 2015; Ignico, 1991; Iivonen et al., 2011; Piek et al., 2013; Tsapakidou et al., 2014; Valentini, 1999; Venetsanou & Kambas, 2004; Vidoni et al., 2014) with 'weak' (weighted mean $SMD_{between}$ = 0.27, 95% CI -0.64 to 1.18) methodological quality showed no statistically significant differences in effect sizes on overall FMS compared with the seven studies (Bonvin et al., 2013; Donath et al., 2015; Hardy et al., 2010; Humeric, 2011; Jones, Riethmuller et al., 2011; Reilly et al., 2006; Roth et al., 2015) of 'high' methodological quality.





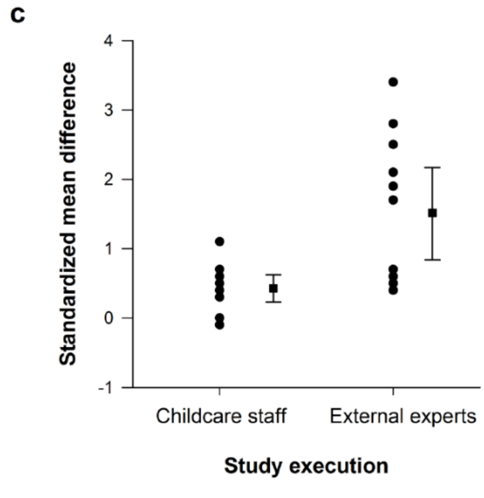


Figure 3 Effect sizes of fundamental movement skill (FMS) interventions according to **a** duration, **b** methodological quality, and **c** study execution of included studies. Filled circles illustrate standardized mean differences ($SMD_{between}$) between intervention and control group for single studies. The filled squares represent weighted mean $SMD_{between}$ with 95% confidence intervals (CI) of the studies combined. The figures show **a** statistically significant higher effect sizes on overall FMS in favor of studies with shorter duration ($SMD_{between}$ = 1.23, 95% CI 0.86–1.61) compared with studies with longer duration ($SMD_{between}$ = 0.32, 95% CI 0.12–0.52); **b** no statistically significant differences in effect sizes on overall FMS for studies of 'high' methodological quality ($SMD_{between}$ = 0.59, 95% CI 0.26–0.93) compared with studies with 'moderate' ($SMD_{between}$ = 1.31, 95% CI 0.74–1.88) and 'weak' ($SMD_{between}$ = 0.76, 95% CI 0.40–1.11) methodological quality; and **c** statistically significant higher effect sizes on overall FMS in favor of studies with external experts ($SMD_{between}$ = 1.54, 95% CI 0.93–2.15) compared with childcare staff ($SMD_{between}$ = 0.41, 95% CI 0.23–0.59)

For total FMS we compared studies that used the TGMD-2 test versus others that used different tests. There was no significant difference in effect sizes between the four studies (Hardy et al., 2010; Ignico, 1991; Jones, Riethmuller et al., 2011; Zask et al., 2012) that used the TGMD-2 and the nine studies

(Bellows et al., 2013; Bonvin et al., 2013; Krombholz, 2012; Piek et al., 2013; Reilly et al., 2006; Roth et al., 2015; Venetsanou & Kambas, 2004; Vidoni et al., 2014; Yin et al., 2012) that used another test (weighted mean $SMD_{between}$ = 0.72, 95% CI -0.50 to 1.94).

Exploratory Analyses

Nine (Goodway et al., 2003; Humeric, 2011; Ignico, 1991; Iivonen et al., 2011; Piek et al., 2013; Reilly et al., 2006; Tsapakidou et al., 2014; Valentini, 1999; Zask et al., 2012) out of 30 studies in this systematic review looked at some aspects of gender differences but results were too heterogeneous to run meta-analyses. Effects in girls compared with boys for total FMS were larger in three (Ignico, 1991; Reilly et al., 2006; Zask et al., 2012) and smaller in one study (Piek et al., 2013). For locomotor skills, no difference in effect sizes were found between the sexes in three studies (Goodway et al., 2003; Tsapakidou et al., 2014; Valentini, 1999). However, consistently larger effects were found for object control skills in boys compared with girls in four studies (Goodway et al., 2003; Humeric, 2011; Iivonen et al., 2011; Valentini, 1999). There was no clear picture regarding characteristics of the interventions (frequency, duration), target population (disadvantaged children, age) or setting (childcare, kindergarten) that explained gender differences in results. Four studies (Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Valentini, 1999) included disadvantaged children or children that were at risk of delay in FMS competence due to socioeconomic or biological factors. Three of these studies (Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999) showed particularly large effect sizes ($SMD_{between}$) for LMS and OCS (2.06–2.76). Figure 3c shows the intervention effects according to the persons who implemented the FMS intervention in childcares or kindergartens. The 11 studies (Alhassan et al., 2012; Donath et al., 2015; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Humeric, 2011; Ignico, 1991; Robinson & Goodway, 2009; Valentini, 1999; Venetsanou & Kambas, 2004; Yin et al., 2012) in which external experts implemented the intervention programs compared with the 12 studies (Bellows et al., 2013; Bonvin et al., 2013; Hardy et al., 2010; Iivonen et al., 2011; Jones, Riethmuller et al., 2011; Krombholz, 2012; Piek et al., 2013; Reilly et al., 2006; Roth et al., 2015; Tsapakidou et al., 2014; Vidoni et al., 2014; Zask et al., 2012) in which childcare or kindergarten teachers were responsible for implementation showed statistically significant higher effect sizes on overall FMS (weighted mean $SMD_{between}$ = 1.46, 95% CI 0.52–2.40). For five studies (Deli et al., 2006; Kelly et al., 1989; Wang, 2004; Weiß et al., 2004), results were not available due to missing SMD, SD, and/or SE or due to the reporting of only single items. Whether studies were more or less effective, was not differentiated by either the setting where FMS interventions took place (kindergarten versus childcare), the use of a theoretical framework on which the intervention was based (yes versus no), or the additional involvement of parents in FMS intervention programs (yes versus no) (data not shown). In addition, we were unable to tease out the most effective intervention approach based on pedagogic concept, the volume, or the content of the interventions to improve and develop FMS.

Discussion

Our systematic review and meta-analyses revealed beneficial effects on overall motor skill proficiency (total FMS score), as well as on object control and locomotor skills in children aged 2–6 years with small-to-large effect sizes following FMS intervention programs conducted in childcare or kindergarten settings. Further, studies of shorter (< 6 months) compared with longer duration (> 6 months) and the integration of external experts rather than implementation of the programs by the usual childcare/kindergarten teachers resulted in higher effect sizes, while the methodological quality of the studies did not play a role. Importantly, due to the low certainty of evidence based on GRADE, findings of this systematic review and meta-analysis have to be interpreted with care. Even though most studies conducted in childcare and kindergarten proved to be effective, we have to acknowledge that the effect estimates and the true effect may likely be substantially different from the current effect estimates as reported in this review. This finding should by no means be interpreted as that FMS interventions in young children should not be done as there is insufficient evidence, but rather, it should be taken as a key message that more high-quality research is needed in the field of FMS interventions in early childhood (van Sluijs & Kriemler, 2016). A higher quality of studies would imply high standard randomization procedures, the careful selection of control groups to prevent cross-contamination (Waters et al., 2011; Waters et al., 2012), the integration of appropriate power analyses to calculate sample sizes needed for group or sub-group analyses (e.g., for gender), and the blinding of assessors for important outcomes such as FMS (Hróbjartsson et al., 2013; Wood et al., 2008). Further, it seems imperative and timely to carefully select and standardize test batteries for FMS assessment (Logan et al., 2017), to use adequate statistical methods including appropriate baseline comparisons as well as the control for important confounders and clusters (Campbell et al., 2012), to assess intervention fidelity (Miller & Rollnick, 2014), and finally to integrate long-term follow-up (Jones, Sinn et al., 2011).

Interpretation of Overall, Subgroup, and Exploratory Analyses

Despite our comprehensive search in seven databases from the year of inception up to August 2015, only 30 studies fulfilled our eligibility criteria, 15 of which (Deli et al., 2006; Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Hashemi et al., 2015; Ignico, 1991; Iivonen et al., 2011; Kelly et al., 1989; Krombholz, 2012; Tsapakidou et al., 2014; Valentini, 1999; Venetsanou & Kambas, 2004; Wang, 2004; Weiß et al., 2004; Yin et al., 2012) were CTs rather than RCTs. There was, however, no major difference in findings and effect sizes between CTs or RCTs (data not shown).

Contrary to physiological considerations of a dose-response principle with the expectation that longer interventions would lead to higher effect sizes, we found that longer interventions showed smaller effect sizes (Fig. 3a). This trend was also documented in other reviews (Logan et al., 2012) and suggests that a loss of compliance and motivation may have occurred with activities provided during FMS interventions becoming monotonous and leading children and caregivers to lose interest over time (Lai et al., 2014). Alternatively, there may have been insufficient adaption of the programs, which need training progression over time to keep up a stimulus (Faigenbaum et al., 2011; Matos & Winsley, 2007).

The methodological quality of the studies was not proportional to the effect sizes of the intervention on FMS (Fig. 3b), suggesting that an overestimation of training on FMS in preschoolers did not occur. It is also reassuring that the overall picture of beneficial effects of interventions on overall FMS, OCS, and LMS was consistent and in accordance with other reviews focusing on children with developmental delays (Pless et al., 2000; Smits-Engelsman et al., 2013) or on children with an older age range (Lai et al., 2014; Morgan et al., 2013). Even in the single test items, findings revealed medium (jumping, throwing, catching, kicking) or at least small (running, hopping, standing long jump, balance) effect sizes. Yet, based on GRADE (Table 2), where we assessed the magnitude of effects and the overall quality of evidence and found that the estimates of FMS interventions in young children are trustworthy, we have little confidence in the effect estimates and it is therefore very probable that the true effect is likely substantially smaller or larger than the effect estimate. Of the five relevant factors that can lower the quality of evidence, four factors showed serious limitations. These included the failure of describing the detailed study design and execution or risk of bias (e.g., no clear description of randomization procedures), the finding of inconsistency or heterogeneity of effects (e.g., statistical heterogeneity of effects with I^2 [80% all outcomes), indirectness or applicability (e.g., important differences in implementation across settings), and a possible publication bias (ESM Fig. S1). Smaller estimates of effects of FMS interventions may, for instance, be found if assessors of FMS are blinded for group assignments (Hróbjartsson et al., 2013; Wood et al., 2008), while larger effects may be found if fidelity regarding the implementation of the intervention is assessed (Miller & Rollnick, 2014), or by the selection of proper control groups without cross-contamination (Waters et al., 2011; Waters et al., 2012).

Although some argue that long-term follow-ups are most relevant when studies show short-term effects, follow-ups should be contingent on the methodological quality of the original trial, irrespective of effect (van Sluijs & Kriemler, 2016). In this review, only seven (Humeric, 2011; Iivonen et al., 2011; Piek et al., 2013; Reilly et al., 2006; Robinson & Goodway, 2009; Roth et al., 2015; Valentini, 1999) of 30 studies included longer-term follow-ups. Of those, three studies (Humeric, 2011; Robinson &

Goodway, 2009; Roth et al., 2015) provided evidence of sustained beneficial effects on FMS 8–12 weeks off intervention ($SMD_{between}$ = 1.80, 95% CI 1.03–2.57; $SMD_{between}$ = 0.59, 95% CI 0.17–1.01; $SMD_{between}$ = 2.67, 95% CI 2.15–3.19), while four studies (Iivonen et al., 2011; Piek et al., 2013; Reilly et al., 2006; Valentini, 1999) with follow-up from 3–12 months off intervention did not find lasting effects. This finding supports the opinion of experts in the field that FMS have to be taught, practiced, and reinforced repeatedly as they do not seem to develop and be maintained naturally (Logan et al., 2012; Morgan et al., 2013; Riethmuller et al., 2009). However, it may be a challenge to find feasible and effective strategies that lead to a sustained FMS proficiency in view of the fading effects with longer-term interventions and the obvious need for experienced teachers.

In order to help us better understand which intervention strategies may or may not work, why, and for whom, we tried to tease out interventions that were more effective than others by stratifying for target groups, the setting, and characteristics of the interventions. Although trials were only included if they examined typically developing young children, four studies (Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999; Valentini, 1999) included disadvantaged children or children that were at risk of delay in FMS competence due to socioeconomic or biological factors. Three studies (Goodway et al., 2003; Goodway & Branta, 2003; Hamilton et al., 1999) showed particularly large effect sizes ($SMD_{between}$) for LMS and OCS (2.06–2.76), possibly because these children may have had greater potential to improve FMS competence (Logan et al., 2012). On the other hand, interventions targeting a completely healthy population of young children may have the problem of attaining a ceiling effect in FMS proficiency. This could be the case when FMS interventions use a FMS outcome test that is mainly built to differentiate typically developing children from those with a motor deficiency rather than having the potential to differentiate skills within a healthy population (Cools et al., 2009). We do not think that this phenomenon has occurred, as in our review, effect sizes for total FMS among those studies that started with mean values below the median at baseline were not different from those that started with above-median values ($SMD_{between}$ = 1.01, 95% CI -0.11 to 2.29). A ceiling effect for FMS intervention results may also be more likely when the age of the target group children is close to the upper limit of the validated age range that is covered by the respective test battery (Logan et al., 2017). This was not the case in most studies in this review. Firstly, they used scaled scores or percentiles for age categories based on half-yearly or yearly steps to adjust for age and maturational effects; and secondly, they used predominantly the TGMD (-2), which covers ages up to 10 years. Nevertheless, several tests that were also used in the included studies have an upper age limit of 6 years (see ESM Table S2), where a ceiling effect might have played a role. As studies usually report mean ages and SDs, the ceiling effect is difficult to assess, but should indeed be considered in future studies.

Although clear gender differences for FMS exist (Barnett et al., 2016; Pedersen et al., 2003; Ulrich, 2000), be it related to differences in physical activity behavior (Cooper et al., 2015) or cultural norms (Cools et al., 2009) that may foster enhanced FMS in boys (e.g., kicking) or girls (e.g., balancing), the reach and responsiveness of girls and boys in interventions targeting FMS may be different as well. Only a few studies in this review scrutinized gender differences. They reported unequivocal results for total FMS (one study (Piek et al., 2013) with higher effect sizes in boys and three studies (Ignico, 1991; Reilly et al., 2006; Zask et al., 2012) with higher effect sizes in girls), consistently better results for object control skills favoring boys (four studies (Goodway et al., 2003; Humeric, 2011; Iivonen et al., 2011; Valentini, 1999)), but no difference in effects for locomotor skills (three studies (Goodway et al., 2003; Tsapakidou et al., 2014; Valentini, 1999)). Although recent primary research focusing on FMS indicated that gender differences in FMS existed in favor of the boys (Barnett et al., 2010; Goodway et al., 2010; Hume et al., 2008; Spessato et al., 2013), FMS was a predictor of physical activity and fitness in adolescence in both sexes (Barnett et al., 2009, 2008). The few gender-differentiated results in our systematic review did not allow for conclusions to be drawn on whether girls or boys profited more from FMS interventions or whether there is a need for and value to be gained from targeting. So far, both sexes seem to profit from FMS interventions. It may be that boys profit more from interventions targeting object control skills, as consistently stronger effects in favor of boys were found in our review (Goodway et al., 2003; Humeric, 2011; Iivonen et al., 2011; Valentini, 1999). Perceived competence, whether preceded (Papaioannou et al., 2006) or as a consequence of actual (motor) competence (Harter, 1978), may have played a role in their motivation to improve object control skills (Barnett, Morgan et al., 2008; Robinson, 2011). However, evidence of a gender difference in the association between actual and perceived FMS in young children is lacking (Liong et al., 2015). As Barnett et al. (2010) suggested, boys may simply obtain more encouragement, positive reinforcement, and stimulation for activities involving object control skills.

Future consideration should therefore be given to the need for a universal or gender-targeted approach, the acceptability and effectiveness of different approaches available for targeting, and the potential positive and negative consequences of either (van Sluijs & Kriemler, 2016). While the setting (kindergarten versus childcare) did not play a role in effectiveness, effects were stronger when the intervention was provided by an external expert in the field of FMS rather than the usual childcare or kindergarten teachers (Fig. 3c). The integration of experts to build up proper FMS programs and educate childcare and kindergarten teams how to teach FMS (Harter, 1980) seems evident (Robinson & Goodway, 2009). These experts bring the combined expertise of knowledge about the development and training of FMS and the pedagogic skills needed to foster actual but also perceived FMS (Harter, 1980). They may also be more skilled at providing the magic intervention ingredient of fun that is identified as a critical component of interventions (Loman, 2008; Neumark-Sztainer et al., 2000) and that may lead to sustained enjoyment (Martínez-Vizcaíno et al., 2014; Ryan & Deci, 2000) and create a motivational climate for teachers and the children (Valentini, 1999). Promising concepts have been used by the integrated studies attempting to integrate these fundamental psychological and pedagogic principles, including programs that specifically focused on a mastery climate (Robinson & Goodway, 2009), or integrated music and dance (Deli et al., 2006; Derri et al., 2001; Tsapakidou et al., 2014; Valentini, 1999; Vidoni et al., 2014). Whatever the concept, an intervention delivering on sustained fun is likely to engage children as well as teachers and promote ongoing involvement, while being enjoyable to deliver (van Sluijs & Kriemler, 2016).

Strengths and limitations

Our review has several strengths. We reviewed all intervention studies aimed at increasing motor skills in young children by including a larger range of literature databases than other reviews (Logan et al., 2012; Morgan et al., 2013; Riethmuller et al., 2009). The focus was on typically developing young children attending childcare or kindergarten in contrast to mainly school-aged individuals (Lai et al., 2014; Morgan et al., 2013) and did not include children with existing motor handicaps or with developmental delays (Pless et al., 2000; Smits-Engelsman et al., 2013). Teams of reviewers worked both independently and in pairs to select eligible studies, assess risk of bias and extract data. Furthermore, we used the GRADE approach to rate our certainty in the evidence and presented findings with the GRADE evidence profiles. Our results are limited by shortcomings of many of the studies that were eligible for our review and led to our ratings of very low certainty for the intervention effects. Reasons for downgrading included limitations in the study design such as CTs or RCTs with unclear randomization procedures and lack of information regarding allocation concealment, and lack of blinding of outcome assessors and data analysts. Moreover, there was a huge variation in intervention content, duration, and intensity, and often an unknown intervention integrity that did not lead to any sort of dose-response in the outcomes (Guyatt, G. H., Oxman, A. D., Sultan, S. et al., 2011). In addition, there was a large heterogeneity of results. This heterogeneity of results may be explained at least in part by the substantial variation in intervention load and strategies, by the use of a wide range of motor test batteries to measure motor skills (Deeks et al., 2008), or by a high chance of a publication bias. The latter is shown in the consistently asymmetrical funnel plots for the overall FMS and the subscales (Guyatt, G. H., Oxman, A. D., Montori, V. et al., 2011) (ESM Fig. S1) and verified by the Egger's test (Egger et al., 1997) (data not shown). The activities in the control group were poorly defined in 19 out of 30 studies, providing room for bias (Waters et al., 2011; Waters et al., 2012). Further limitations were the exclusion of studies written in languages other than English or German, the skipping of the forward tracking of studies (e.g., looking at studies that cite the included articles), and the conversion of the motor skill test results to the most commonly used test battery among the eligible studies of this review as suggested by GRADE (Guyatt et al., 2013). These applied motor skill test batteries may appear to measure similar constructs and show high correlations in change scores; however, responsiveness of instruments may differ substantially and lead to important between-study heterogeneity (Puhan et al., 2006). Nevertheless, in our review effect sizes for total FMS were similar in studies that used the reference test (TGMD-2) versus those that used another test, suggesting the different responsiveness was not a major problem. Moreover, the use of process-oriented FMS tests that measure how (well) a movement skill is measured or product-oriented FMS assessment batteries in which quantity aspects (e.g., time or distance) are measured provide diverging information (Logan et al., 2017). Although the two means of assessment are reasonably related, they also show substantial variation of correlations that may have affected the pooled results in meta-analyses (Cools et al., 2009; Logan et al., 2017).

Implications for Clinical Practice

From a very young age, proficiency in FMS is related to relevant aspects of health including higher physical activity and physical fitness, reduced obesity, and enhanced social and cognitive skills (Leonard & Hill, 2014; Lubans et al., 2010). Developing motor skills enables the young child to interact with the social and physical environment. As children grow, motor skills are crucial to engage in a large variety of movements and play activities, starting with simple running or throwing a ball to complex physical interactions with peers in the playground or during (organized) sports. Moreover, mutual interactions between motor and cognitive performance and executive functions take place (Diamond, 2000; Roebers & Kauer, 2009) and motor control is used to guide the way in which the surroundings are perceived and processed through ongoing interactions between brain, body, and environment (Smith, 2005). Thus, improving actual motor skill development, but also perceived motor competence may provide enhanced opportunities for the development of a variety of perceptual, social, and cognitive skills, and may further be influenced in turn by these abilities in iterative interactive cycles (Leonard, 2016; Robinson, 2011; Robinson et al., 2015; Smith & Thelen, 2003). Given these clinically relevant and plausible benefits, improving actual and perceived motor skills should be a priority public health strategy to stimulate physical activity in youth, ideally implemented at the childcare or kindergarten level where a large number of young children can be reached very early (Logan et al., 2012; Riethmuller et al., 2009; Robinson et al., 2015) and without stigmatization of those that need it most.

Based on this and previous reviews (Logan et al., 2012; Morgan et al., 2013; Riethmuller et al., 2009), all aspects of FMS should and can be taught in childcare, kindergarten, or similar settings, including object control skills, locomotor skills, balance, or more complex FMS tasks (see Fig. 2 and ESM Figs. S2–4), preferably by the integration of an expert teacher (Robinson & Goodway, 2009) and by intervening over time (Logan et al., 2012; Morgan et al., 2013; Riethmuller et al., 2009). Careful emphasis should be placed on maintaining attractive and potent intervention programs for children and teachers as effects may fade with time due to a loss of motivation or insufficient physical stimulus. To progress the field, more theory-driven research (Robinson et al., 2015) needs to be done to tease out the most effective intervention components (length and intensity of sessions, timing, duration, content, context such as with or without music, the integration of dance items), as well as possible effect modifications by age (Ackerman, 1988), gender (Veldman et al., 2017), obesity (Barnett et al., 2016), physical activity (Stodden et al., 2008), perceived motor competence (Barnett et al., 2011; Barnett, Morgan et al., 2008), physical fitness (Cattuzzo et al., 2016), characteristics of the setting (Bonvin et al., 2013), and teachers (Barnett et al., 2016).

Scientifically, the best strategy to improve FMS in young children has yet to be determined in future studies that will hopefully address current limitations. The conduct and publication of well-designed evaluations of well-defined interventions using the same standardized assessment tool for young children, preferably combining process- and product-oriented FMS test items (Logan et al., 2017), with international reference values allowing direct comparison (also of intervention effects) worldwide is crucial to advance the field of FMS promotion in children and help us better understand which intervention strategies may or may not work, why, and for whom (van Sluijs & Kriemler, 2016). Consequently, this may then lead to realistic and clinically sound implementation strategies to foster FMS proficiency starting at an early age.

Conclusion

This review indicates positive effects of childcare- or kindergarten-based interventions on FMS proficiency in young children. Yet, the evidence base is low and we have little confidence in the effect estimate. As the true effect is likely to be substantially different from the reported estimate of the effect, results must be considered with care. Nevertheless, FMS-enhancing programs may have an important role in children attaining motor skill proficiency as the basis for a physically active lifestyle (Barnett et al., 2009) and to profit from a variety of physiological, social, and cognitive health benefits (Hardy et al., 2012; Lubans et al., 2010). Future high-quality research is needed to establish certainty in effectiveness of FMS training in young children by searching for optimal programs, looking at dose-response relations and long-term sustainability. Additional references can be found in the ESM (Ames, 1992; Bellows et al., 2013; Bruininks & Bruininks, 2005; Cools et al., 2009; Deli et al., 2006; Fisher et al., 2005; Folio & Fewell, 2000; Hardin & Peisner-Feinberg, 2005; Henderson et al., 2007; Kakebeeke et al., 2012; Krombholz, 2011; Meyer, 2012; Moher et al., 2009; Numminen, 1991, 1995; Piek et al., 2012; Ulrich, 2000; Zachopoulou et al., 2010; Zimmer & Volkamer, 1987).

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Study II

Associations between Measures of Physical Fitness and Cognitive Performance in Preschool Children

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Abstract

Given that recent studies report negative secular declines in physical fitness, associations between fitness and cognition in childhood are strongly discussed. The preschool age is characterized by high neuroplasticity which effects motor skill learning, physical fitness, and cognitive development. The aim of this study was to assess the relation of physical fitness and attention (including its individual dimensions (quantitative, qualitative)) as one domain of cognitive performance in preschool children. We hypothesized that fitness components which need precise coordination compared to simple fitness components are stronger related to attention. Physical fitness components like static balance (i.e., single-leg stance), muscle strength (i.e., handgrip strength), muscle power (i.e., standing long jump) and coordination (i.e., hopping on one leg) were assessed in 61 healthy children (mean age 4.5 ± 0.6 years; girls n = 30). Attention was measured with the "Konzentrations-Handlungsverfahren für Vorschulkinder" [concentration-action procedure for preschoolers]). Analyses were adjusted for age, body height, and body mass. Results from single linear regression analysis revealed a significant ($p < 0.05$) association between physical fitness (composite score) and attention (composite score) (standardized ß = 0.40), showing a small to medium effect ($F^2 = 0.14$). Further, coordination had a significant relation with the composite score and the quantitative dimension of attention (standardized ß = 0.35; $p < 0.01$; standardized ß = − 0.33; $p < 0.05$). Coordination explained about 11% (composite score) and 9 % (quantitative dimension) of the variance in the stepwise multiple regression model. The results indicate that performance in physical fitness, particularly coordination, is related to attention in preschool children. Thus, high performance in complex fitness components (i.e., hopping on one leg) tend to predict attention in preschool children. Further longitudinal studies should focus on the effectiveness of physical activity implementing coordination and complex exercises at preschool age to examine cause-effect relationships between physical fitness and attention precisely.

Background

An increasing number of children suffer from the so-called exercise deficit disorder which is a condition characterized by reduced levels of physical activity that are below current recommendations of at least 60 minutes daily moderate-to-vigorous physical activity (Myer, Faigenbaum et al., 2013). As a consequence, researchers have reported low levels of physical fitness and even tendencies of negative secular declines in physical fitness, particularly for cardiorespiratory endurance (especially between the years 1981 to 2000) (Tomkinson et al., 2019) and muscle strength and power in school-aged children (Fühner et al., 2021; Masanovic et al., 2020). Thereby, the amount of declines in physical fitness reported within the mentioned reviews varied between countries (Fühner et al., 2021; Masanovic et al., 2020; Tomkinson et al., 2019). Given that physical activity and fitness are rather robust phenomena that track from childhood to adulthood (Kristensen et al., 2008), it is important to promote physical activity and fitness at an early age to enable a healthy upbringing. Longitudinal studies (Fedewa & Ahn, 2011) underline the positive effects of physical activity and physical fitness by showing that regular performance of aerobic exercise and perceptional motor training (3/week) over 36 weeks (academic school year) has the potential to improve not only cardiorespiratory endurance (i.e., aerobic fitness) but also cognitive (e.g., intellectual quotient) and academic performance (e.g., math and reading achievement) in school-aged children. Wick and colleagues (2021) demonstrated that even in preschool children a 10-weeks (3/week) integrative strength-dominated exercise program was effective in significantly increasing physical fitness (i.e., standing long jump) and cognitive performance (i.e., attention). Moreover, cross-sectional studies in preschool children confirmed these findings. Greier and Drenowatz (2019) showed weak correlations between balancing backwards ($r = 0.21$), jumping to and fro sideways ($r = 0.24$), and visuospatial working (measured with the “Human-Drawing-Test”) in children 5 to 6 years old. Similarly, Voelcker-Rehage (2005) reported significant moderate relations between reaction time ($r = 0.41$), coordination ($r = 0.30$), and fine motor skills ($r = 0.34$) and cognitive performance (i.e., visual processing) in 4- to 6-year-old children. Niederer and colleagues (2011) were focusing only on a sum score of attention exploring weak correlations between measures of aerobic fitness ($r = 0.25$), agility ($r = -0.11$), and attention in 245 preschool children. Accordingly, a systematic review in 4 to 16 year old children found that fine motor skills, bilateral body coordination, and speed of movement (e.g., foot tapping, running in a zigzag) had moderate to strong correlations with cognitive performance (i.e., memory, visual processing, executive functions, fluid intelligence) compared to gross motor and object control skills (van der Fels et al., 2015). These findings demonstrate that especially in early childhood different domains of physical fitness, particularly coordination (Greier & Drenowatz, 2019; Niederer et al., 2011; van der Fels et al., 2015), seem to be related to cognitive performance (i.e., attention, memory, visual processing). The reported associations between physical fitness and cognitive performance as well as the impact of physical exercise programs on cognitive performance are most likely caused by increased brain oxygenation based on an increased blood flow (Querido & Sheel, 2007). In addition, an increased neurotransmitter concentration which encourage information processing and an enhanced growth factor concentration which stimulate brain plasticity and neuronal cell connectivity are possible explanations how physical activity and exercise may effect cognitive performance (Ploughman, 2008; Trudeau & Shephard, 2010). Thereby, the preschool age plays a decisive role during maturation. First, early childhood compared to late childhood and adolescence is characterized by accelerated cognitive maturation and rapid cognitive developmental trajectories (Anderson et al., 2001). Second, the acquisition and mastery of fundamental movement skills predominantly evolve during the preschool years (Stodden et al., 2008) emphasizing the close relationship between motor and cognitive development during early age (Davis et al., 2011). Fundamental movement skills build the foundation to achieving and maintaining physical fitness (Cattuzzo et al., 2016). Both parameters mutually influence one other (Faigenbaum & Bruno, 2017) and are essential parts for a continuously active lifestyle. In the context of this study, physical fitness is defined as the ability to carry out daily tasks with alertness, vigor, and sufficient energy (Caspersen et al., 1985). Third, possible deficits in motor or cognitive development that may negatively influence following developmental stages (Fühner et al., 2021; Masanovic et al., 2020; Tomkinson et al., 2019) may be detected as early as possible.

Accordingly, the aim of this study was to assess the relationships of physical fitness with attention and its individual dimensions (quantitative, qualitative). Further, we aimed on finding physical fitness components (i.e., static balance, muscle strength, power, and coordination) that predict the variance of attention in a convenience sample of healthy preschool children. Cognitive performance comprises a whole set of mental actions and processes that contribute to perception, memory, attention, and intellect (Donnelly et al., 2016). In our study we are concentrating on attention as it has an impact on school readiness (Perera, 2005), positively influence the transition from preschool to primary school and predict academic achievement in the long term during the school years (Alavi et al., 2019; Pagani et al., 2012). Moreover, attention composes a quantitative (working speed) and a qualitative (working accuracy) dimension which characterize levels of attentional capacity. Given that preliminary research has shown better cognitive performance in physically fit children (Fedewa & Ahn, 2011; Greier & Drenowatz, 2019; Niederer et al., 2011), we further hypothesized that fitness components which need precise coordination during execution (e.g. hopping on one leg) and require higher order cognitive skills are stronger related to attention compared to fitness components which are more fundamental constructs without the need of a high skill level (i.e., handgrip strength) (van der Fels et al., 2015).

Methods and materials

An exploratory study design was used to examine physical fitness and cognitive performance in preschoolers from a convenience sample of three kindergartens located in eastern regions of Germany (Wick et al., 2021). Sixty-one children (boys n = 31; girls n = 30) with a mean age of 4.5 ± 0.6 years and a range of 4 to 6 years (i.e., 42 – 74 months, 58.7 ± 7.3 months) participated in the study, which was approved by the local ethics research committee (submission No. 34/2018). Additionally, the study was conducted in accordance with the latest version of the Declaration of Helsinki. Prior to the start of the study, parents or legal representatives received written information on the aims of the study and the study design, including potential risks and benefits. Parents or legal representatives of all participating children provided their written informed consent before the study started. An a priori power analysis was computed using G x Power (Version 3.1.9.2, University of Kiel, Kiel, Germany (Faul et al., 2007)). The F-test family (linear multiple regression analysis) was used with a type I error of 0.05 and a statistical power of 0.80 (type II error rate) for physical fitness components (i.e., static balance, muscle strength, power, coordination) as independent (predictor) variables. With references to a study by Moradi et al. (2019) who included five predictor variables (e.g., muscle strength, muscular endurance, flexibility, speed, agility) and one dependent variable (either information processing speed or inhibitory control), we included four predictor variables and one dependent variable (composite score of attention) in our statistical model. Thus, a sample size of 53 participants would be needed to explore a medium to strong effect size of $F^2 = 0.25$ (Cohen, 2013) for our regression analysis. In the present study we are referring to test-retest reliability using intra class coefficients (ICC) for all physical fitness and cognitive tests which were assessed in our pilot study (pre-post testing of control group n = 22; (Wick et al., 2021)). The pilot study was conducted between August and November 2018 using a quasi-experimental study design (a 2-group repeated-measures design).

Anthropometric data

Anthropometric data (body height, body mass and BMI) was measured using standardized procedures (Wick et al., 2021). Body mass index (BMI) was calculated using the standardized equation (mass/height [in kilograms per square meter]).

Physical fitness

Static balance, muscle strength, power, and coordination were assessed in exercise rooms located within the kindergarten by specifically trained assessors. Every child was tested individually after performing one familiarization trial and after having received standardized verbal instructions and visual demonstration regarding the test procedures. We reported test-retest reliability using intra class coefficients (ICC) for all physical fitness tests which were assessed in our pilot study (pre-post testing of control group n = 22 (Wick et al., 2021)).

Single-leg stance test

Static balance was evaluated by using the single-leg stance test (Ortega et al., 2008). Children had to stand barefoot with eyes opened on the dominant leg which was assessed through the ball kick tests (Balogun et al., 1994). The stopwatch was started as soon as the nondominant leg was lifted in front with hip and knee joints both flexed at 90°. Children performed one trial up to a maximum of 30 seconds. If they were not able to pass 2 seconds in the first trial, they were asked to perform a second trial (Kakebeeke et al., 2013). A child was considered as not capable of performing the single-leg stance test if he or she performed 2 unsuccessful trials. Time was measured by a stopwatch to the nearest one-tenth of a second and was stopped if the nondominant leg touched the floor or the child started hopping to achieve stability. The interrater reliability for the single-leg- stance test from our pilot study was ICC = 0.76 (Wick et al., 2021).

Standing long jump test

As a proxy of lower limbs muscle power, standing long jump performance was assessed. Children were instructed to jump with both feet starting from a parallel standing position as far as possible in horizontal direction aiming on landing on both feet (Ortega et al., 2008). The jumping distance from start to landing was taken using a measuring tape to the nearest 1.0 cm. A trial was considered as not valid if children lost balance during landing and fell backwards. Children performed 2 trials and the best trial was used for further analysis. In our pilot study the interrater reliability was ICC = 0.89 (Wick et al., 2021).

Handgrip strength test

Muscle strength was assessed using a handheld dynamometer (Jamar plus digital with LCD display). Therefore, children performed the handgrip strength test with the dominant hand which was assessed through reports of the kindergarten teachers (Scharoun & Bryden, 2014) as the preferred hand when performing fine and gross motor tasks. Prior to the handgrip strength test, the hand's span length of each participating child (diagonal length from tip of the little finger/pinky to the tip of the thumb) was assessed. According to the span length, we used level 1 (girls ,14 cm; boys ,10.8 cm) or level 2 (girls 14–19.1 cm; boys 10.8–20.1 cm) to enable an individualized biomechanical position for the handgrip strength test. The Jamar handheld dynamometer has 5 notches (levels) which can be adjusted depending on the individually hand span length. While sitting on a chair with shoulders relaxed and elbows flexed at 90°, the dynamometer had to be pressed continuously at maximum effort for at least

3–4 seconds (Molenaar et al., 2008). The best of two trials was used for further analysis. Muscle strength was measured to the nearest 0.1 kg. In children aged 4–6 years, the handgrip strength test has proven to be reliable (ICC = 0.83; (Wick et al., 2021)).

Hopping on one leg test

For the assessment of coordination, the hopping on right/left leg test (Krombholz, 2011) was operationalized and performed alternately once with each leg. Children were instructed to hop on one leg as often as possible to a maximum of 20 hops. If takeoff and landing was achieved on the same foot and at least one time, a hop was considered valid. The interrater reliability in our pilot study was ICC = 0.60 for the right and ICC = 0.88 for the left leg, respectively (Wick et al., 2021). For further analyzes, we computed a composite score as on overall measure of coordination by using the mean z-scores from each leg (right/left).

Cognitive performance

Attention as one domain of cognition was assessed in quiet rooms in the respective kindergartens for each child individually by one specifically trained assessor.

Konzentrations-Handlungsverfahren für Vorschulkinder

We applied attention with the Konzentrations-Handlungsverfahren für Vorschulkinder [concentration-action procedure for preschoolers] (KHV-VK) (Ettrich & Ettrich, 2006). Children had to sort 40 cards with familiar images as fast as possible but within a maximum time of 10 minutes in 4 different boxes. On every card, children had to find the key image (no, single, or double key images) in order to sort the card into the correct box. The KHV-VK measures and analyzes sorting time as quantitative and error quote as qualitative dimension of attention. The ICC in our pilot study were ICC = 0.43 for sorting time and ICC = 0.73 for correct cards (Wick et al., 2022). Further, the test has been validated in children aged 4–6 years and proved to be sufficiently valid as a diagnostic procedure (Ettrich & Ettrich, 2006). We calculated a composite score as an overall measure of attentional capacity using the mean of the z-scores of the individual dimensions of the KHV-VK (raw scores of sorting time as quantitative and error quote as qualitative dimension).

Statistical analyses

Normality of data was assessed and confirmed using the Shapiro-Wilk test. Accordingly, descriptive statistics were reported as group mean values and standard deviations (SD). The relationship between measures of physical fitness and cognitive performance were tested using two-tailed Pearson correlation coefficients for continuous variables and Spearman rank correlation for nominal variables.

According to Cohen (Cohen, 2013), a correlation coefficient of $r < 0.3$ is considered weak, $0.3 \leq r < 0.5$ moderate, and $r \geq 0.5$ strong. We defined age, sex, body height, body mass as covariates that may influence physical fitness and cognitive performance in children. Prior to the regression analyses, key assumptions were checked. One individual case was identified as outlier and excluded from further analyses as linear regression models are not robust towards outliers. All other key assumptions of our regression models were confirmed. Single linear regression models (unadjusted vs. adjusted for potential covariates) were calculated for attention (composite score and individual dimensions - dependent variable) and the composite score of physical fitness (independent variable). Subsequently, the relation between attention (composite score and individual dimensions - dependent variable) and the four measures of physical fitness (static balance, muscle strength, power, and coordination – independent variables) were analyzed by stepwise multiple linear regression models to find physical fitness components that predict the variance of attention in early childhood. To ascertain if a predictor variable has a practically meaningful effect, we interpreted Cohen's F for the single linear regression models and Cohen's F^2 for the multiple linear regression models. For Cohen's F, we calculated the square root of (R^2 divided by 1-R^2) considering an effect as small = 0.10, medium = 0.25, or large = 0.40. For Cohen's F^2, R^2 was divided by 1-R^2 considering an effect as small = 0.02, medium = 0.15, or large = 0.35 (Cohen, 2013). The significance level was set at $p < 0.05$. As no performance differences were found between boys and girls, statistical analyses were computed using pooled data. All statistical analyses were performed using SPSS version 25.0 (IBM SPSS Statistics, Armonk, NY, USA).

Results

Total descriptive characteristics of age, anthropometry, physical fitness, and cognitive performance are presented in Table 1. No injuries were reported during physical fitness testing. In terms of correlation analyses between covariates (age, sex, body height, body mass), physical fitness, and cognitive performance, we found that standing long jump, hopping on one leg, and handgrip strength were related to age ($p \leq 0.05$) showing medium to strong correlations coefficients (r = 0.32-0.59). Body height and body mass showed significant ($p \leq 0.05$) medium to strong correlations (r = 0.27 - 0.66) with standing long jump, hopping on one leg, handgrip strength, and the qualitive dimension of the KHV-VK. Thus, age, body height, and body mass were included in the regression models as covariates. Additionally, all four measures of physical fitness were significantly ($p \leq 0.01$) correlated with each other and with the composite score of
attention ($p \leq 0.05$).

Table 1 Descriptive characteristics

Variables	Girls *(n = 30)* Mean ± *SD*	Boys *(n = 31)* Mean ± *SD*	Total *(N = 61)* Mean ± *SD*	*p* (Cohen's *d*) Between group differences
Age and anthropometry				
Age (years)	4.5 ± 0.6	4.5 ± 0.7	4.5 ± 0.6	0.769 (0.06)
Age (months)	57.9 ± 7.5	59.6 ± 7.2	58.7 ± 7.3	0.413 (0.21)
Body height (cm)	109.5 ± 6.3	112.0 ± 4.9	110.8 ± 5.7	0.089 (0.45)
Body mass (kg)	19.3 ± 3.2	19.2 ± 2.2	19.2 ± 2.7	0.874 (0.04)
BMI (kg/m²)	16.0 ± 1.5	15.2 ± 1.1	15.6 ± 1.4	0.033 (0.57)
Physical fitness				
Single-leg stance (max. 30 s)	13.6 ± 8.5	11.3 ± 8.0	12.5 ± 8.3	0.286 (0.29)
Standing long jump (cm)	77.8 ± 16.7	78.7 ± 22.4	78.3 ± 19.7	0.874 (0.04)
Hopping on right leg (max. 20)	14.3 ± 6.9	11.9 ± 7.7	13.2 ± 7.3	0.210 (0.33)
Hopping on left leg (max. 20)	12.7 ± 7.0	12.7 ± 7.5	12.7 ± 7.2	0.992 (0.01)
Composite score (coordination)	0.1 ± 0.9	-0.1 ± 0.9	-0.001 ± 0.9	0.454 (0.20)
Handgrip strength (kg)	7.1 ± 1.5	7.5 ± 1.9	7.3 ± 1.7	0.350 (0.25)
Composite score (physical fitness)*	0.02 ± 0.7	-0.07 ± 0.9	-0.02 ± 0.8	0.654 (0.11)
Cognitive Performance				
Sorting time KHV-VK (in min)	7.2 ± 1.6	6.9 ± 2.0	7.1 ± 1.9	0.455 (0.20)
Correct cards KHV-VK (number)	30.6 ± 8.2	31.1 ± 6.8	30.9 ± 7.4	0.823 (0.06)
Composite score (attention)	-0.1 ± 0.8	0.1 ± 0.7	0.00 ± 0.76	0.526 (0.17)

BMI = Body mass index; * mean of the z-scores of each of the four physical fitness tests

In the single linear regression analyses (Table 2), the composite score of physical fitness was positively associated to the composite score of attention before and after adjusting for age, body height, and body mass (standardized ß = 0.40 - 0.43; p < 0.05). The effect size for the association between physical fitness and attention was considered small to medium in the adjusted model. The relationship between the composite score of physical fitness with the individual dimensions of attention (sorting time - quantitative; correct cards - qualitative) however, did not remain significant after adjustment.

Table 2 Single linear regression analyses using attention as dependent and physical fitness as predictor variables

	Physical fitness (composite score)					
	R^2	ß-Coeff.	r^3	95% CI	p-value	Effect size
Attention (composite score)						
unadjusted model	0.183	0.43	0.43	0.172 - 0.609	**0.001**	**F = 0.47**
adjusted model*	0.126**	0.40	0.34	0.091 - 0.630	**0.010**	**F^2 = 0.14**
Attention (sorting time in min)						
unadjusted model	0.102	-0.32	-0.32	-1.376 - -0.166	**0.013**	**F = 0.34**
adjusted model*	0.067**	-0.36	-0.31	-1.604 - -0.131	0.102	F^2 = 0.07
Attention (correct cards, number)						
unadjusted model	0.094	0.31	0.31	0.490 – 5.014	**0.018**	**F = 0.32**
adjusted model*	0.069**	0.21	0.19	-0.808 – 4.668	0.098	F^2 = 0.07

95% CI = 95% confidence interval; ß-Coeff. = standardized ß-coefficient; r^3 = partial correlation coefficient - association between dependent and predictor variables of regression analyses; * adjusted for age, body height, body mass; ** adjusted R^2

The stepwise multiple linear regression analyses revealed a significant positive association between coordination (hopping on one leg) and the composite score of attention (standardized ß = 0.35; $p < 0.01$) showing a small to medium effect size (Table 3). Static balance, muscle strength, and power had not been included in the model as they were not significantly predicting attention in addition to coordination. Moreover, coordination also predicted the quantitative dimension of attention "sorting time" (standardized ß = -0.33; $p < 0.05$). No physical fitness component significantly predicted the qualitative dimension of attention "correct cards".

Table 3 Stepwise multiple linear regression analyses using attention as dependent and physical fitness as predictor variables

	Physical fitness (four single items)					
	R^2	ß-Coeff.	r^3	95% CI	p-value	Effect size
Attention (composite score)						
Coordination**	0.106*	0.35	0.35	0.068 – 0.448	0.009	$F^2 = 0.12$
Attention (sorting time in min)						
Coordination**	0.090*	-0.33	-0.33	-1.239 - -0.141	0.015	$F^2 = 0.10$
Attention (correct cards, number)						
none**	-	-	-	-	-	-

95% CI = 95% confidence interval; ß-Coeff. = standardized ß-coefficient; r^3 = partial correlation coefficient -association between dependent and predictor variables of regression analyses; * adjusted R^2; ** only those physical fitness components that predicted attention (composite score, quantitative and qualitative dimension) are noted here

Discussion

Our findings indicate that physically fitter 4- to 6-year-old children (motor composite score) showed significantly better attentional capacity (composite score) than less fit children with a significant small-medium effect ($F^2 = 0.14$). Additionally, our results illustrate that coordination as assessed by the hopping on one leg test had the strongest relation with the composite score and the quantitative dimension of attention. The physical fitness component coordination explained about 11% and 9% of the variance of attention with a weak to medium effect size.

Regarding the relation between physical fitness (motor composite score) and attention (single linear regression models) we cannot compare our results with other studies. There is no study available that analyzed the relationship between a total motor score and attention (composite score, individual dimensions of attention separately) in preschool children. Yet, there are studies reporting significant correlations between composite motor scores of physical fitness and domains of cognitive performance others than attention (e.g., visuospatial working) in preschoolers (Davis et al., 2011; Greier & Drenowatz, 2019).

In accordance with the study hypothesis, our results show that coordination is related to attention. As a proxy of coordination, we assessed the hopping on one leg test which is a complex and demanding exercise measuring dynamic balance, muscle strength, muscular endurance, bilateral body coordination, and coordination of rhythm. The neuromuscular demands during the execution are highly cognitively determined. While hopping, motor control and motor regulation are constantly needed to make up the performance in hopping (feedback-control mechanisms). Those mechanisms lead to co-activations between different parts of the central nervous (Diamond, 2000) which may stimulate motor performance, attention, and especially working speed (quantitative dimension of attention – sorting time), simultaneously and could explain the associations in our study. Our results are in accordance with the literature. Although, van der Fels et al. (2015) did not specifically focus on attention, they found that fine motor skills, bilateral body coordination, and speed of movement (e.g., foot tapping, running in a zigzag) were significant associated with memory, visual processing, executive functions and fluid intelligence in children. The authors assumed that the complex structure of physical exercises which were demanding and needed precise coordination during execution were stronger related to cognitive performance than simple and less complex exercises. Other studies support these findings by showing for instance that bilateral body coordination, the speed of movement (i.e., foot tapping) and agility had the strongest associations with fluid intelligence and attention in preschool children (Davis et al., 2011; Niederer et al., 2011; Planinsec, 2002). Thereby, higher levels of attentional capacity will prepare preschool children for school entry (Perera, 2005) and facilitate the transition from preschool to primary school. Additionally, academic achievements in primary school are related to attention at preschool age (Pagani et al., 2012). Given that the other fitness components (e.g., static balance, muscle strength, and power) could not improve the explained variance of the dependent variable (i.e., composite score and quantitative dimension of attention) they had not been included in the stepwise multiple regression models. These results are partly in line with the literature (Greier & Drenowatz, 2019; Niederer et al., 2011; Voelcker-Rehage, 2005). Niederer and colleagues (2011) could not find an association of dynamic balance with attention nor for the relation between standing long jump and visuospatial working (Greier & Drenowatz, 2019) or visual processing (Voelcker-Rehage, 2005) or handgrip strength and visual processing (Voelcker-Rehage, 2005). The authors presumed that the tasks mentioned above were simpler to perform, less complex, and therefore required lower cognitive demands.

Nevertheless, the null results of the relation between static balance, muscle strength, power and attention do not mean that those fitness components are not important for a child's development during preschool age. Regardless of their relationship to one another (transfer effects), physical and cognitive development are capabilities which are highly "plastic" during early age (Anderson et al., 2001; Lloyd & Oliver, 2012). To maximize a child's potential of a healthy and optimal development, physical fitness and cognitive performance have to be promoted and trained, whether separately or together. Niederer and colleagues (Niederer et al., 2011) found out that future improvements of attentional capacity at school age was related to the former fitness level at preschool age which illustrates the close relationship between motor and cognitive development (Davis et al., 2011).

Strength and limitations

The present study includes four different measures of physical fitness (i.e., static balance, muscle strength, power, and coordination) which were objectively assessed in children 4 to 6 years. We were focussing on attention composed of a quantitative (sorting time – working speed) and a qualitative (correct cards –working accuracy) dimension (attentional capacity) which we included in our statistical analyses separately. Further, we used two linear regression models to precisely analyze the relationship between physical fitness and attention. First, we calculated single linear regression analyses including possible covariates (i.e., age, body height and body mass). Second, stepwise multiple linear regression analyses were computed to find physical fitness components that predict the variance of attention in early childhood. Nonetheless, there are some limitations that have to be discussed. The cross-sectional design of our study neither allows cause-and-effect relationships nor an interpretation of direction of the association between physical fitness and attention. Furthermore, we included a relatively small none-representative sample size (N = 61). The participating children were selected from 3 kindergartens located in eastern Germany by convenience. Thus, more longitudinal studies with a representative sample under consideration of further covariates (e.g., socio-demographic, socio-economic background, parent's attitude towards physical activity) are needed to examine the relationship of physical fitness and cognitive performance precisely and to detect the direction of association.

Conclusion

The results of the present study indicate that higher performance in physical fitness is related to better attentional capacity already at preschool age. This association was mainly driven by a complex task of coordination (e.g., hopping on one leg) rather than by simple fitness tasks (e.g., static balance, muscle strength, and power). Educators, teachers, and parents should be aware of the close relationship between motor and cognitive development during preschool age (Davis et al., 2011). Especially complex, joyful exercises requiring permanent motor control and motor regulation may positively interact with cognitive tasks (Diamond, 2000; Myer et al., 2015). Nevertheless, more longitudinal or interventional research is needed to examine cause-effect relationships between physical fitness and attention at preschool age preferably using a larger randomly selected sample of preschoolers.

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Wick, K., Kriemler, S. & Granacher, U. (2021). Effects of a Strength-Dominated Exercise Program on Physical Fitness and Cognitive Performance in Preschool Children. *Journal of strength and conditioning research, 35*(4): 983–990.

Study III

Effects of a Strength-Dominated Exercise Program on Physical Fitness and Cognitive Performance in Preschool Children

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Abstract

Childhood is characterized by high neuroplasticity that affords qualitative rather than quantitative components of physical activity to maximize the potential to sufficiently develop motor skills and foster long-term engagement in regular physical activity. This study examined the effects of an integrative strength-dominated exercise program on measures of physical fitness and cognitive performance in preschool children. Children aged 4–6 years from 3 kindergartens were randomized into an intervention (INT) group (n = 32) or a control group (n = 22). The 10-week intervention period was conducted 3 times per week (each session lasted 30 minutes) and included exercises for the promotion of muscle strength and power, coordination, and balance. Pre and post training, tests were conducted for the assessment of muscle strength (i.e., handgrip strength), muscle power (i.e., standing long jump), balance (i.e., timed single-leg stand), coordination (hopping on right/left leg), and attentional span (i.e., "Konzentrations-Handlungsverfahren für Vorschulkinder" [concentration-action procedure for preschoolers]). Results from 232 repeated-measures analysis of covariance revealed a significant ($p \leq 0.05$) and near significant ($p = 0.051$) group x time interaction for the standing long jump test and the Konzentrations-Handlungsverfahren. Post hoc tests showed significant pre-post changes for the INT ($p < 0.001$; $d = 1.53$) but not the CON ($p = 0.72$; $d = 0.83$). Our results indicate that a 10-week strength-dominated exercise program increased jump performance with a concomitant trend toward improvements in attentional capacity of preschool children. Thus, we recommend implementing this type of exercise program for preschoolers.

Introduction

The Centers for Disease Control and Prevention and the World Health Organization (WHO) recommend that children aged 3–5 years should be physically active throughout the day for at least 60 and up to 180 minutes to promote growth and development (Bull et al., 2020; CDC, 2020). Early promotion of health-enhancing physical activity and fitness in kindergarten has thus been subject to many research studies over the past years (Goldfield et al., 2016; Okely et al., 2020). These studies confirm that many children do not follow these guidelines. Finger et al. (2018) reported that less than half of the participating kindergarten children aged 3–6 years (42.5% girls; 48.9% boys) met the WHO physical activity recommendations of 60 minutes per day. As a consequence, low physical fitness levels and negative secular trends have been reported for various components of physical fitness (Shigaki et al., 2019) and for overweight and obesity (Ng et al., 2014). More specifically, a study including English children aged 10–10.9 years showed a significant decline for measures of muscle strength over a 10-year period ranging between -6.3% for handgrip strength and -27.0% for sit-up performance (Cohen et al., 2011). In addition, Tomkinson and Olds (2007) reported the global picture on secular trends in aerobic fitness. These authors showed a significant decline of -0.36% per year for aerobic fitness in youth.

Using an elegant description of the phenomenon, Myer et al. (2013) recently introduced the term “exercise-deficit disorder” if children do not adhere to WHO physical activity guidelines (i.e., less than 60 minutes per day). The long-term negative consequences of the exercise-deficit disorder are deficits in motor skill competence, and movement confidence, sedentary behavior, and an increased risk of suffering from adverse health effects (Myer, Faigenbaum et al., 2013; Robinson et al., 2015; Schwarzfischer et al., 2019). Given that physical activity behavior is a rather robust phenomenon that tracks from later childhood to adulthood (Kristensen et al., 2008), it is important to implement intervention programs to promote physical activity and fitness at an early age when habits are still formed. Although WHO (Bull et al., 2020) and Centers for Disease Control and Prevention (CDC, 2020) guidelines provide quantitative recommendations on daily physical activity, these guidelines do not take motor skill learning into consideration. Childhood is characterized by high neuroplasticity that affords adequate exercise stimuli and professional instruction as well as feedback to promote and consolidate motor skill learning. Experts have postulated that integrative exercise programs are needed during childhood that include motor-skill enriched and intermittent activities such as core strength and stability, coordination and agility, balance, muscular fitness (i.e., muscle strength, muscle power, local muscular endurance), and fundamental movement skills (Myer et al., 2015). A broad foundation of physical fitness, especially muscular fitness, lays the fundamental development for complex and sport-specific skills and movement patterns (Faigenbaum & Bruno, 2017). Thus, exercise programs should predominantly focus on the qualitative rather than the quantitative component of physical activity (Myer et al., 2015) to maximize a child's potential to sufficiently develop motor skills and foster the long-term engagement in regular physical activity (Lloyd et al., 2015; Myer et al., 2011).

Integrative strength-dominated exercise programs have proven to be effective in increasing muscle strength (Faigenbaum et al., 2005; Faigenbaum et al., 2015) and cognitive skills in primary school-aged children (Myer et al., 2011; Myer et al., 2015; Myer, Kushner et al., 2013). To the authors' knowledge, such a study does not exist with preschoolers. However, there is evidence that programs promoting physical fitness and motor skills are successful even in kindergarten children (Niederer et al., 2011; Roth et al., 2015; Wick et al., 2017). In addition, there is debate on the appropriate timing of initiating strength training with children (Lloyd et al., 2014; Lloyd et al., 2015). It is unresolved whether a strength-dominated exercise program in the long term is even more effective if it is started already at preschool age. Lloyd and Oliver (2012) emphasized the importance of promoting motor skills and physical fitness (e.g., speed, muscle strength) at all developmental stages starting during early childhood.

We therefore performed a strength-dominated kindergarten-based exercise program aiming to increase physical fitness and cognitive performance in healthy children aged 4–6 years. With references to studies conducted in school-aged children (Faigenbaum et al., 2015; Myer, Kushner et al., 2013), we hypothesized that the applied intervention program is more effective to enhance primary (e.g., muscle strength of upper body, muscle power of lower body) and secondary (e.g., static balance, coordination, attention) outcomes compared with a regular physical activity promoting kindergarten curriculum. Our study hypothesis is based on the assumption that a strength-dominated exercise program is particularly effective if started during the early developmental stages (i.e., kindergarten) (Faigenbaum & Bruno, 2017) to lay a foundation for motor skill learning. This may again positively affect physical activity behavior during the later stages of life (Lloyd et al., 2015; Roth et al., 2015).

Methods

Experimental approach to the problem

This study was conducted between August and November 2018 using a quasi-experimental design (a 2-group repeated-measures design) to evaluate the effects of a 10-week strength-dominated kindergarten-based exercise program on measures of physical fitness and cognitive performance in preschool children. A convenience sample was selected that includes 3 kindergartens located in east Germany (i.e., Federal State of Brandenburg). Selection criteria were similarity in size, available resources (i.e., staff, play equipment), and funding body (i.e., run by public institutions). The participating kindergartens were cluster randomized into either an intervention (INT) or a control (CON) group. Before the start of the study, all 3 kindergartens offered similar physical activity or sport programs during daily care. Pre- and posttests were carried out at the same time of the day by trained assessors (sport scientists, bachelor and master students). The participating children were familiarized with all test procedures before testing. After completion of the intervention period, children from the CON received the same supervised intervention program.

Subjects

An a priori power analysis with reference to the study of Faigenbaum et al. (2015) was computed using G x Power (Version 3.1.9.2; University of Kiel, Kiel, Germany) and the F test family (Faul et al., 2007) with a desired Bonferroni adjusted significance level of 0.025 (type I error) for 2 primary outcomes, and a statistical power of 0.80 (type II error rate) for the effects of a strength-dominated exercise program on components of physical fitness. The analysis revealed that 41 subjects would be needed to find medium-sized group x time interaction for physical fitness components. We expected a 15% dropout rate over the course of the study because of a loss of motivation, illnesses, or injuries.
Fifty-four children aged 4–6 years with a mean age of 4.5 ± 0.7 years (i.e., 48–74 months, mean 59.5 ± 7.0 months; mean ± SD) were enrolled in the present study. Exclusion criteria were trisomy and chronic diseases, such as respiratory tract diseases or diabetes. In addition, subjects were excluded if orthopedic disorders (e.g., acute, overuse injuries) were diagnosed 6 months before the start of the study. Kindergartens were cluster randomized into either an intervention (INT, *n* = 32) or a control (CON, *n* = 22) group. Baseline anthropometric data are provided in Table 1.

Table 1 Baseline anthropometric characteristics.

Variables	INT *(n = 32)* Mean ± *SD*	CON *(n = 22)* Mean ± *SD*	*p* (Cohen's *d*) Between-group differences
Gender (m/f)	16/16	12/10	
Age (years)	4.6 ± 0.8	4.5 ± 0.5	0.455 (0.15)
Age (months)	60.1 ± 8.1	58.6 ± 5.2	0.446 (0.22)
Body height (cm)	112.4 ± 5.4	110.0 ± 5.6	0.116 (0.44)
Body mass (kg)	20.2 ± 2.7	18.5 ± 2.1	0.015 (0.70)
BMI (kg/m²)	16.0 ± 1.4	15.2 ± 1.0	0.043 (0.66)

INT = intervention group; CON = control group; BMI = Body mass index

Before the start of the study and any form of data collection, parents or legal representatives received written information on the aims, the procedures, and the risks and benefits of the study and data collection. Written informed consent was obtained from all parents or legal representatives as all participating children were aged ,18 years and also from all the subjects. This study was approved by the Ethics Research Committee of the University of Potsdam, Germany (submission No. 34/2018). The study was conducted in accordance with the latest version of the Declaration of Helsinki.

Procedures

Experimental Groups. The strength-dominated kindergarten-based exercise program was developed by a trained exercise scientist in close collaboration with experienced kindergarten teachers. The intervention program was performed in the kindergartens and was carried out by the own kindergarten staff. Before the start of the intervention, 2 workshops were provided for the participating kindergarten teachers. Each workshop lasted 90 minutes and contained information about the overall aim of the program, the contents of the 30 sessions including detailed descriptions of all exercises. Furthermore, questions with regards to movement competency, training-load (volume and intensity), and equipment were answered. Over the 10-week training period, 3 exercise sessions were conducted per week (Monday, Wednesday, Friday). Because of a limited attentional span of preschoolers, each session lasted 30 minutes (Riethmuller et al., 2009) and was offered in the mornings. Each week, the intervention program focused on the promotion of different aspects of physical fitness mainly to improve not only muscle strength and muscle power but also balance, coordination, and motor skills. Balance exercises included walking on tiptoes, standing on one leg (eyes opened/closed), balancing on ropes or benches. In addition, coordination exercises, such as handling (i.e., throwing, catching, kicking, dribbling) objects (i.e., balloon, ball, stick, sheet, hoop), moving like animals, moving to the music, were offered using different forms of small games. Nevertheless, strength exercises constituted the main part. Furthermore, basic elements from gymnastics were selected to complete the strength-dominated program. A description of the strength and gymnastic exercises are provided in Table 2. To ensure an adequate level of intensity during each session, numbers of repetitions or time under tension were provided for each exercise. The degree of difficulty and intensity was progressively increased according to the individual progress of the children. The structure of each session was basically the same. It started with an 8-minute warm-up (i.e., small games), a 12- to 15-minute main session (e.g., muscle strengthening exercises), and a 5- to 10-minute cooldown (i.e., relaxation and social games). All children of the INT conducted the same intervention contents of the program. The waiting CON continued their usual kindergarten curriculum, which included 1 exercise session per week (30–45 minutes) and at least 1 hour of free play per day. Members of the kindergarten staff were asked not to increase physical activity levels of the waiting CON over the course of the study. After the intervention period, the CON received the same intervention program as the intervention children.

Table 2 Strength exercises included in the strength-dominated kindergarten program

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Strength exercises										
Countermovement jumps	1 x 5	n/a	1 x 10	2 x 10	n/a	2 x 15	2 x 15 BW	2 x 20	n/a	2 x 25
Countermovement jumps with rotation	n/c	n/a	1 x 10	2 x 10	n/a	2 x 15	n/a	n/a	n/a	n/a
Lunges	1 x 8/leg	n/a	n/a	n/a	n/a	n/a	n/a	2 x 8/leg	n/a	n/a
Ankle hops	n/a	n/a	n/a	1 x 10	n/a	n/a	2 x 10	2 x 15	n/a	n/a
Lateral jumps	n/a	n/a	n/a	1 x 10	n/a	n/a	2 x 10	n/a	n/a	n/a
Single leg jumps	n/a	n/a	n/a	2 x 5/leg	n/a	n/a	n/a	n/a	n/a	2 x 10/leg
Squats with partner	n/a	n/a	n/a	2 x 5	n/a	n/a	n/a	2 x 10	n/a	n/a
Quadruped walk	1 x 15s	n/a	n/a	n/a	2 x 15s	n/a	n/a	n/a	2 x 20s	n/a
Front plank	n/a	2 x 8s	n/a	n/a	2 x 15s	n/a	n/a	2 x 20s	2 x 30s	2 x 30s legs open/close
Bridging	n/a	2 x 8s	n/a	n/a	n/a	n/a	n/a	2 x 10s	3 x 10s	n/a
Stretch seat*	3 x 3s	3 x 5s	3 x 10s	n/a	3 x 12s	3 x 15s	4 x 15s	n/a	n/a	n/a
Straddle seat*	3 x 3s	3 x 5s	3 x 10s	n/a	3 x 12s	3 x 15s	4 x 15s	n/a	5 x 15s	5 x 15s
PP lifting arms and legs*	n/a	2 x 5s	2 x 10s	n/a	2 x 12s	2 x 15s	3 x 15s	n/a	4 x 15s	5 x 15s
SP lifting arms and legs*	n/a	2 x 5s	2 x 10s	n/a	2 x 12s	2 x 15s	3 x 15s	n/a	4 x 15s	5 x 15s
Table position*	n/a	n/a	n/a	n/a	n/a	2 x 10s	n/a	n/a	3 x 10s	4 x 10s

BW = backward; n/a = not applicable – no exercises were offered during that week; PP = prone position; s = seconds; SP = supine position
* basic elements from gymnastics

Testing Procedures. Measurements were performed at baseline and after the 10-week intervention period. All tests were conducted at the kindergartens between 8.30 AM and noon by the same trained assessors who were blinded to group allocation. Test time and sequence were similar between pre- and posttests. Physical fitness of the participating children was tested in specific exercise rooms located within the kindergartens. Anthropometric and cognitive testing was realized in quiet rooms in the respective kindergartens. Every child was tested individually. The entire test program lasted between 20 and 30 minutes per child. All primary and secondary outcomes were tested within a 2-week period. All participating children received standardized verbal instructions and a visual demonstration regarding test procedures. Thereafter, each child performed 1 familiarization trial before the test trial.

Anthropometrics. Body height was determined to the nearest 0.5 cm, and body mass was measured without shoes and in light indoor clothing using an electronic scale to the nearest 0.1 kg (Tanita BC-730). Body mass index (BMI) was calculated using the standardized equation (mass/height [in kilograms per square meter]).

Primary Outcomes. In accordance with our strength-dominated kindergarten-based exercise program, we defined muscle strength of the upper body and muscle power of the lower body operationalized through the handgrip strength test and the standing long jump test as primary outcomes. Thereby, muscle strength of the upper body was evaluated applying the handgrip strength test using a hand dynamometer (Jamar plus digital with LCD display). Before the performance of the handgrip strength test, the diagonal length (span length) of the hand was assessed in centimeters (from the tip of the little finger/pinky to the tip of the thumb) of the participating children. Of note, the Jamar handheld dynamometer has 5 notches (levels). According to the span length of a child's hand, we used level 1 (girls < 14 cm; boys < 10.8 cm) or level 2 (girls 14–19.1 cm; boys 10.8–20.1 cm) to enable an individualized biomechanical position for the handgrip strength test. Thereafter, subjects were placed on a chair with shoulders relaxed and elbows flexed at 90° and were required to press the dynamometer continuously at maximum effort for at least 3–4 seconds (Molenaar et al., 2008). The test was performed twice with the dominant hand, the best trial was used for further analysis. The dominant hand was determined by reports of the kindergarten teachers (Scharoun & Bryden, 2014) as the preferred hand when performing fine and gross motor tasks. Muscle strength of the upper body was measured to the nearest 0.1 kg. The handgrip strength test proved to be reliable (intraclass correlation coefficient [ICC] of 0.91 long-term 29 days) in children aged 4–6 years (Molenaar et al., 2008). Additionally, the National Institutes of Health has tested feasibility, reliability, and validity of fitness tests in children aged 3 years and older and recommended to conduct a handgrip strength test using a hand dynamometer to assess muscle strength of the upper body (Reuben et al., 2013). The standing long jump test was used to assess muscle power and coordination of the lower limbs. For this purpose, children started from a parallel standing position with arms hanging loose to the side and were instructed to jump with both feet as far as possible in a horizontal direction with the aim of landing on both feet (Ortega et al., 2015). The test was performed twice, and the best value of the 2 trials was used for further analysis. The jumping distance was documented using a measuring tape to the nearest 1.0 cm. If children lost balance during landing and fell backward, the trial was considered invalid, and children had to try again. The standing long jump test has proven to be reliable (test-retest reliability $r = 0.68$ long term 8 months) in 4 year olds (Krombholz, 2011).

Secondary Outcomes. Static balance was assessed barefoot and with eyes opened using the single-leg stance test (Ortega et al., 2015). Before testing, the dominant leg was determined using the ball kick test. The kicking leg was defined as the dominant leg (Balogun et al., 1994). Thereafter, children had to stand in straight position holding the nondominant leg in front with hip and knee joints both flexed at 90°. The stopwatch was started as soon as one leg was lifted and stopped when the child touched the floor with the nondominant leg or started jumping to achieve stability. If children were not able to pass 2 seconds in the first trial, they had to try again (Kakebeeke et al., 2013). After 2 unsuccessful trials up to 2 seconds, the test was considered as not possible because the child was not capable of performing the single-leg stand. For test results > 2 seconds, time was measured by stopwatch to the nearest one-tenth of a second up to a maximum of 30 seconds. The single-leg stance test is a reliable test-retest reliability $k_w = 0.45$ (Kakebeeke et al., 2013) and valid (Ortega et al., 2015) test to analyze static balance in early childhood. Moreover, the National Institutes of Health has recommended the single-leg stance test for the assessment of static balance in children aged 3 years and older (Reuben et al., 2013). Secondary outcomes also included coordination operationalized through the hopping on right/left leg test (Krombholz, 2011). Children were instructed to hop on one leg as often as possible to a maximum of 20 hops. The test was performed alternately once with each leg. A hop is considered valid when takeoff and landing was achieved on the same foot and at least one time. The one-leg hopping test proved to be reliable (right $r = 0.84$ left $r = 0.82$) in 4- to 6-year-old children (Krombholz, 2011). Attention as one domain of cognition was applied with the Konzentrations-Handlungsverfahren für Vorschulkinder (concentration-action procedure for preschoolers) (KHV-VK) (Ettrich & Ettrich, 2006). Thereby, children had to sort 40 cards with familiar images into 4 different boxes within 10 minutes according to no, single, or double key images. Sorting time and error quote analyzed quantitative and qualitative dimensions of the KHV-VK on attention. The test has been validated in children aged 4–6 years and proved to be sufficiently valid as a developmental diagnostic procedure. Test-retest reliability was $r = 0.88$ for sorting time and $r = 0.67$ for number of correct cards (Ettrich & Ettrich, 2006).

Statistical analyses

All analyses were performed using SPSS version 25.0 (IBM SPSS Statistics, Armonk, NY). Normal distribution of data was tested and confirmed using the Shapiro-Wilk test. Accordingly, data are presented as group mean values and SDs. Subsequently, a t-test for independent samples was calculated to determine significant baseline between-group differences. If baseline between-group differences were detected, the respective baseline values were included as covariates in the statistical model to adjust for baseline differences. The effects of a strength-dominated exercise program on variables of physical fitness and cognitive performance were analyzed using a separate 2 (“group”: INT vs. CON) x 2 (“time”: pre vs. post-test) repeated-measures analysis of covariance (ANCOVA). In case of statistically significant group x time interactions, group-specific post hoc tests were calculated to identify the comparisons that were statistically significant. Furthermore, to estimate effect sizes, partial eta-squared were taken from ANCOVA output and converted to Cohen’s d. Effect sizes were used to ascertain if an effect was practically meaningful. According to Cohen (2013), effect size of ≤ 0.19 indicates trivial, $0.20 \leq d \leq 0.49$ small, $0.50 \leq d \leq 0.79$ medium, or $d \geq 0.80$ large effects. The significance level was set at $p < 0.025$ for the primary outcomes. Moreover, test-retest reliability was assessed for primary and secondary outcome measures using ICCs. For this purpose, data from pre-post testing of the CON was used (Shrout & Fleiss, 1979).

Table 3 Main and interaction effects of the strength-dominated exercise program for primary and secondary outcome measures

	INT			CON			*p* (Cohen's *d*)		
Variables	Pre Mean ± *SD (95 % CI)*	Post Mean ± *SD (95 % CI)*	Delta (%)	Pre Mean ± *SD (95 % CI)*	Post Mean ± *SD (95 % CI)*	Delta (%)	Main effect: time	Main effect: group	Interaction: group x time
Primary outcomes									
Standing long jump (cm)*	73.8 ± 15.6 (68.1 - 79.5)	85.9 ± 16.1 (80.0 - 91.7)	19.3	93.0 ± 17.2 (86.0 - 99.7)	87.8 ± 16.3 (80.8 - 94.9)	-5.6	0.077 (0.51)	0.014 (0.72)	0.001 (1.18)**
Handgrip strength (kg)*	7.3 ± 1.6 (6.8 - 7.9)	8.0 ± 1.7 (7.4 - 8.6)	9.6	7.5 ± 1.6 (6.8 - 8.2)	8.5 ± 1.7 (7.8 - 9.2)	13.3	0.001 (1.04)	0.403 (0.24)	0.458 (0.21)
Secondary outcomes									
Fitness									
Single-leg stand (max. 30 s)*	10.1 ± 8.1 (7.2 - 13.0)	13.7 ± 9.1 (10.5 - 17.0)	35.6	17.2 ± 8.2 (13.7 - 20.7)	19.1 ± 9.2 (15.1 - 23.0)	11.0	0.031 (0.62)	0.005 (0.83)	0.481 (0.20)
Hopping on right leg (max. 20)*	11.6 ± 7.0 (9.0 - 14.2)	12.4 ± 6.9 (9.9 - 14.9)	6.9	16.7 ± 7.1 (13.7 - 19.8)	18.1 ± 7.0 (15.1 - 21.1)	8.4	0.143 (0.42)	0.006 (0.82)	0.699 (0.11)
Hopping on left leg (max. 20)*	12.3 ± 7.6 (9.5 - 15.2)	13.8 ± 7.1 (11.2 - 16.5)	12.2	14.3 ± 7.7 (11.0 - 17.6)	17.4 ± 7.2 (14.3 - 20.5)	21.7	0.004 (0.87)	0.175 (0.40)	0.337 (0.28)
Cognition									
Sorting time KHV-VK (in min)	7.2 ± 2.0 (6.5 - 7.9)	5.6 ± 1.4 (5.0 - 6.1)	22.2	6.4 ± 1.7 (5.5 - 7.2)	5.9 ± 1.6 (5.2 - 6.5)	7.8	0.001 (1.09)	0.484 (0.20)	0.051 (0.58)**
Correct cards KHV-VK (number)	31.9 ± 5.3 (29.4 - 34.3)	33.0 ± 5.7 (30.8 - 35.1)	3.4	31.5 ± 8.3 (28.4 - 34.5)	32.9 ± 6.0 (30.3 - 35.5)	4.4	0.187 (0.39)	0.871 (0.06)	0.840 (0.06)

* adjusted pre and post-test values of physical fitness outcomes, adjusted for body mass ** Post hoc tests were calculated INT = intervention group; CON = control group; KHV-VK = Konzentrations-Handlungsverfahren für Vorschulkinder

Table 4 Intraclass correlation coefficients for all included measures

Measures	ICC*
Primary Outcomes	
Handgrip strength test	0.829
Standing long jump test	0.888
Secondary Outcomes	
Single-leg stance test	0.755
HRL	0.597
HLL	0.876
Sorting time KHV-VK	0.428
Correct cards KHV-VK	0.727

* Data used from control group during pre- and post-testing. HRL = hopping on right leg; HLL = hopping on left leg; ICC = intraclass correlation coefficient; KHV-VK = Konzentrations-Handlungsverfahren für Vorschulkinder

Results

All children of the INT received the intervention contents as allocated and completed the study according to the methodology described above. None of the participating children reported any test- or training-related injuries over the study period. The attendance rate of INT was 83 ± 13%. At baseline, significant between-group differences were found for body mass ($p < 0.05$; $d = 0.70$) and BMI ($p < 0.05$; $d = 0.66$). Children from INT compared with CON were slightly heavier (8.4%) and had a higher BMI (5.0%). Differences were also found for the single-leg stance test ($p < 0.05$; $d = -0.73$) and the standing long jump test ($p < 0.005$; $d = -0.89$) in favor of the CON. No significant between-group baseline differences were found for age or sex. Inferential statistics for primary and secondary outcomes are reported in Table 3. Table 4 illustrates ICCs for all primary and secondary outcome measures.

Primary outcomes

Our analyses showed a significant group x time interaction ($p < 0.001$; $d = 1.09$) for the standing long jump test. Post hoc analysis revealed significant pre-post changes for the INT ($p < 0.001$; $d = 1.53$) but not the CON ($p = 0.72$; $d = 0.83$) as shown in Figure 1. No statistically significant interaction effect was found for handgrip strength.

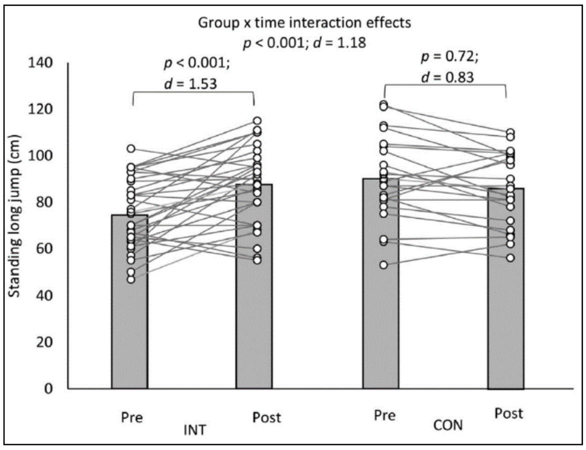

Figure 1 Effects of a strength-dominated exercise program on standing long jump performance in children aged 4–6 years. Data are presented in group means (grey bar) and individual scores.
CON = control group; INT = intervention group

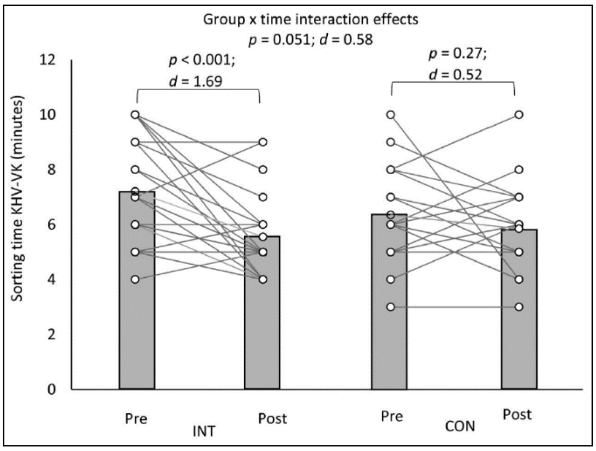

Figure 2 Effects of a strength-dominated exercise program on attentional span (sorting time of the KHV-VK) in children aged 4–6 years. Data are presented as group means (grey bar) and individual values.
CON = control group; KHV-VK = Konzentrations Handlungsverfahren für Vorschulkinder, INT= intervention group

Secondary outcomes

No statistically significant interaction effects were observed for the single-leg stance and the hopping on right/left leg test. A near significant group x time interaction ($p < 0.051$; $d = 0.58$) was found for attentional span (sorting time, quantitative dimension KHV-VK), with the post hoc analysis revealing an improvement in the INT with 22.2% ($p < 0.001$; $d = 1.69$) compared with no significant change in the CON ($p = 0.27$; $d = 0.52$) as presented in Figure 2. No significant interaction was observed for the qualitative dimension (number of correct cards) of the KHV-VK.

Discussion

This is the first study that examined the effects of a strength-dominated kindergarten-based exercise program on different components of physical fitness and cognitive performance in healthy children aged 4–6 years. The main findings showed that a 10-week strength-dominated exercise program resulted in larger gains in jump performance and concomitant trends toward improved attentional span in preschool children compared with active control children who followed the regular kindergarten curriculum. In accordance with the study hypothesis, our findings indicate that the strength-dominated exercise program induced a significant large effect ($d = 1.09$) for the primary outcome muscle power of the lower body and a near to significant medium effect ($d = 0.58$) for the secondary outcome attention (quantitative dimension of the KHV-VK). It can be assumed that a strength-dominated exercise program 3 times per week over a 10-week period seems to be successful to develop jump performance and tend to improve attentional capacity in healthy preschool children.

Our findings with regards to the standing long jump are in accordance with the literature. Behringer et al. (2011) reported similar results in their meta-analysis, demonstrating significant improvements in jump performance after structured strength training programs for school-aged children. In contrast, studies from Faigenbaum et al. (2005; 2015) found no treatment effects for the standing long jump in primary school children as response to an 8-week training period. The authors assumed that the content of the strength program focusing on truncal muscular power (i.e., abdominal, hip, and lower back) and the effective traditional physical education lessons of the CON may have been the reason for a lack of treatment effects (Faigenbaum et al., 2015). For the primary outcome handgrip strength, we could not find a significant intervention effect, although integrative exercise programs have been shown to improve muscle strength of the upper body measured with the push-up test in primary school children (Faigenbaum et al., 2015). It can be anticipated that on the one hand, the contents and the design of the present intervention program did not affect muscle strength of the upper body, and on the other hand, the assessment method using a hand dynamometer did not display possible interaction effects.

Our findings for the single-leg stance test (main time effect $p < 0.05$; $d = 1.09$; no significant interaction effect $p = 0.481$; $d = 0.20$) are in contrast to a study conducted by Kordi et al. (2016) who found significant interaction effects for static balance after a 12-week strength training program in primary school children with developmental coordination disorders. For the hopping on right/left leg test, we cannot compare our results to other studies because there is no study available that applied the hopping on right/left leg test. Of note, Krombholz (2012) obtained a general motor skill score including hopping on the right/left leg in his intervention study. He reported that children of the INT following a physical activity enhancing program over 20 months significantly improved their motor performance (general motor skill score) compared with the CON (Krombholz, 2012).

Our null results for the single-leg stance and hopping on one leg test could be further explained by the small sample size and the large variance in children's performance. Additionally, the content and design of our intervention program, targeting muscle strength (of upper and lower body), core strength, and overall coordination may not have affected static balance skills and jumping coordination abilities such as hopping on one leg in kindergarten children. For the secondary outcome cognitive performance, children of the INT tended to improve their attentional span by becoming faster in sorting 40 cards measured by the KHV-VK compared with the CON. Our findings are in line with preliminary evidence published in studies and reviews for school-aged children (Myer et al., 2015; Myer, Kushner et al., 2013) showing that higher levels of physical activity and physical fitness foster attention and concentration. Moreover, our data imply that already kindergarten children appear to respond to the structured weekly strength-dominated activity bouts by improving their attentional capacity compared with an active CON that performed regular physical activity during kindergarten.

However, following the 10-week study period, observable overall time effects for the handgrip strength test, the single-leg stance test, and the hopping on left leg test can be reported (Table 4), indicating that the unspecific physical activity sessions 30–45 minutes once a week of the CON and also biological maturation appear to have occurred in concert. Besides, biological maturation, growth, and genetic factors (Malina et al., 2004) also play a major role especially in childhood when biological changes occur consistently and fast. Nevertheless, the kindergarten age seems to be an important time to target muscle strength in an age-appropriate way. Accordingly, children should perform muscle strengthening exercises in kindergarten because sufficient strength levels are needed for motor skill learning (Faigenbaum & Bruno, 2017). This fact is underlined by a work of Lloyd and Oliver (2012) showing that the long-term development of motor skills, physical fitness components (i.e., muscle strength), and especially their trainability is possible at all age stages starting with early childhood. The main reasons for these arguments are that motor and cognitive capabilities are highly "plastic" and responsive to adequate exercise stimuli (Myer et al., 2015) and professional instruction (Tomporowski et al., 2011) during that age period. Moreover, a broad foundation of physical fitness components, such as muscle strength, lays the fundamental development for complex and sport-specific skills and movement patterns (Faigenbaum & Bruno, 2017).

This study has some limitations that warrant discussion. First, our study involved a relatively small (N = 54), and none-representative sample as the participating children were selected from 3 kindergartens located in east Germany (i.e., Federal State of Brandenburg). Second, we observed baseline differences between the intervention and control group for body mass, BMI, the standing long jump test, and the single-leg stance test. To adjust for these baseline between-group differences, we computed an ANCOVA and not an analysis of variance. Third, selection bias may have occurred in terms of the participating kindergartens which already had programs for the promotion for physical activity and fitness. Finally, we cannot rule out that the children's parents may have increased the physical activity behavior of their children over the course of the study. We expect though that this potential effect was the same in INT and CON, which is why it should not have caused bias.

Practical applications

Findings from this study indicate that a strength-dominated kindergarten-based exercise program resulted in significant and near to significant improvements in jump performance and attentional capacity in preschool children. With reference of the findings of this study, kindergarten teachers are advised to implement muscle strengthening exercises in the regular kindergarten physical activity curriculum, to build a solid foundation of muscular fitness (i.e., muscle strength, muscle power, local muscular endurance), which is a prerequisite for motor skill development. Moreover, the program was instructed by qualified kindergarten teachers who were trained before the intervention period to provide appropriate delivery of intervention contents with professional instruction, feedback, and interaction. It is important to involve members of the kindergarten staff in the preparation and implementation of physical activity programs because this may lead to intrinsic motivation, sustainable long-term effects, and sharpen the awareness of the topic (van Sluijs & Kriemler, 2016).

The kindergarten is a well-suited setting to promote physical activity and fitness because children can be reached irrespective of their family's socioeconomic background (Wick et al., 2017). The participating children had the opportunity to engage in 3 weekly physical activity sessions, learn new movement skills, and improve their physical fitness in a joyful and age-appropriate environment (van Sluijs & Kriemler, 2016). As an additional finding that was not measured objectively, the participating kindergarten staff reported that the intervention also resulted in improved psychosocial behavior, particularly in younger (4 years) children.

The applied intervention program proved to be age appropriate, safe, joyful, and feasible with no injuries occurring during the intervention period. Nevertheless, more research is needed to examine the effects of resistance training in kindergarten children on measures of physical fitness and cognitive performance using larger samples.

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