Effects of increased physical education and motor skills acquisition on scholastic performance

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Published on idrottsforum.org 2017-09-07

Current recommendations for physical activity in children focus on the quantitative aspects of physical activity and health-related components of physical fitness. The importance of motor skill acquisition early in life is often overlooked, which may limit qualitative aspects of interventions, such as motor skill development, socialization and enjoyment of exercise. The aim in this article was to present current knowledge regarding effects of physical education (PE) programs and motor skills practice on cognitive function and scholastic performance. Searching for reviews and meta-analyses was done in ERIC via Ebsco, Google Scholar, MEDLINE, PUBMED, PsycINFO, SPORTDiscus, Summons, and Research Gate. The main findings show that cognition is grounded in perceptual-motor experiences within social and cultural contexts and perceptual-motor behaviors can facilitate readiness to learn and scholastic performance in school. Motor skill screening provides a valuable tool for identifying children in need of adapted support in motor skill development. Motor skill observations are recommended at school start to increase the predictability of later achievement. Specific 'adapted' interventions should be offered to children with motor skill deficits in order to benefit motor development and motivation for participation in physical activities.

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Current recommendations for physical activity (PA) in children focus on the quantitative aspects of physical activity and health-related components of physical fitness (e.g. aerobic fitness, muscular strength, muscular endurance, flexibility and body composition). The importance of motor skill acquisition early in life is often overlooked, which may limit qualitative aspects of interventions, such as motor skill development, socialisation and enjoyment of exercise (Myer, Faigenbaum, Edwards, Clark, Best, & Sallis, 2015). Perceptual-motor behaviors can, according to Lobo, Harbourne, and Dusing (2013) facilitate readiness to learn and scholastic performance in school. Cognition is grounded in perceptual-motor experiences within social and cultural contexts. Executive functions (inhibitory control, working memory, and cognitive flexibility) are sometimes more predictive of academic achievements than even IQ or socioeconomic status (Diamond & Ling, 2016).

Aim

The aim of this review is to give an account of some of the current knowledge regarding effects of physical education (PE) programs and motor skills practice on cognitive function and scholastic performance in children and youth. Another aim is to propose potential conclusions and recommendations for children and youth based on the relationship between motor skills and cognition/scholastic performance.

Theoretical background

According to the motor skill learning theory, preadolescence is the optional time to develop and maintain fundamental motor skills (FMS), reaction time, and academic attainment (Myer, Faigenbaum, Edwards et al., 2015). The Motor Skills as Ground for Learning model [in Swedish: Motorisk Utveckling som Grund för Inlärning (MUGI)], used e.g. in the Bunkeflo intervention (Ericsson, 2003), is built on the assumption that embodied cognition is attained through sensory–motor interactions and experienced automatization of FMS. The MUGI theory was developed with inspiration from the concept self-efficacy in the social cognitive theory (Bandura, 1997). According to Bandura (1997) cognitive guidance is especially important in early phases of skill development, when a cognitive representation of the skill is formed. It is of importance that any feedback given is structured to build a sense of personal efficacy as well as a specific skill. Corrective feedback that highlights successes and directs attention to relevant aspects of sub skills aids the development of proficiency. Informative feedback improves the performance as well as facilitates observational learning for similar activities. The aim with continued practice is that skills become fully integrated and are executed with ease. Once a skill becomes routinized, it no longer requires higher cognitive control. The execution can then be regulated by lower sensory-motor systems in managing recurrent task demands.

> After people develop adequate ways of managing situations that recur regularly, they act on their perceived efficacy without requiring continuing directive or reflective thought. (Bandura, 1997, p. 34)

This disengagement of thought from action performing has considerable functional value. Having to think about details in every skilled activity would consume most of the brain's attentional and cognitive resources. The automation of complex skills involves several processes. Bandura (1997) outlines three major steps:

1. Mergerization, i.e. segments of the skill are merged into larger skills until it becomes a fully integrated routine that no longer requires cognitive organization or linkage.
2. Production of contextual linkages. Practiced actions repeatedly in the same situations are linked to recurrent contexts so that performers respond instantly without having to think about what to do.
3. Shift of attention from execution to result of the action.

Based on earlier research and practise of the MUGI model (Ericsson, 2003; 2008a; 2008b) some theoretical assumptions regarding the relationships between physical activity and scholastic performance can be summarized as follows: Improvements and automatization of fundamental motor skills lead to increased physical self-esteem, which give better prerequisites for attention and comfort in school, which lead to increased motivation to learn and to attend classes. An illustration of this positive spiral is shown in figure 1.

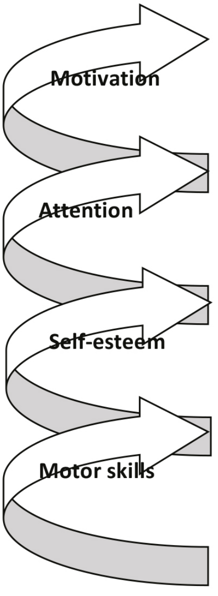

Figure 1. *Theoretical assumptions in the MUGI model: Improvements and automatization of fundamental motor skills lead to increased self-efficacy and physical self-esteem, which give better prerequisites for attention and comfort in school, which lead to increased motivation to learn and to attend classes.*

Methods

Searching for relevant reviews and meta-analyses was performed in Spring 2016 using ERIC via Ebsco, Google Scholar, MEDLINE, PUBMED, PsycINFO, SPORTDiscus, Summons, and Research Gate. Additional studies were identified through back-searching bibliographies. Inclusion criteria were trials conducted 2000-2016, with an intervention of physical activity in children younger than 19 years that measured cognitive, executive functions or academic outcomes. The following search words were used in different combinations: Control/experimental group, Experiment, Effect size, Matched groups, Physical activity/education, Exercise/physical fitness, Motor coordination, Spatial Ability, Psychomotor Skills, Fundamental Movement Skills (FMS), Academic achievement/attainment, Student promotion/learning, Scholastic grades/marks, Cognition, and Executive Function.

Effects of Physical Education (PE) programs

Many schools have reduced or eliminated Physical Education (PE), in an effort to increase students' academic performance. However, no empirical evidence exists to suggest that the elimination of PE is related to higher academic achievement. In fact, empirical evidence show that aerobic fitness, but not muscle strength and flexibility fitness, has a positive relation to academic achievement, whereas body mass index (BMI) has a negative relation. Research studies support PE as an important component of children's health and wellbeing (Hillman, Erickson, & Kramer, 2008). Many of the educational benefits claimed for PE and school sport are however dependent on contextual and pedagogic variables. Type of activity and psychological factors (e.g. self-esteem and depression) could mediate the association between physical activity and academic performance (Bailey et al., 2009).

In 39 intervention studies Fedewa and Ahn (2011) found significant effects on children's achievement and cognitive outcomes from perceptual motor training, regular PE classes and aerobic training. No significant effects were found from resistance/circuit training on children's achievement and cognitive outcomes. Significantly higher effect sizes were found when physical activity was provided three compared to two times per week. Elementary school age children were found to benefit the most. Cognitively impaired or physically disabled children appeared to benefit even more than typically developing children.

Costa, Abelairas-Gomez, Arufe-Giraldez, and Barcala-Furelos (2015) emphasize the importance of PE and qualified PE teachers in child development. In an experiment, motor skills activities were used to enhance children's overall development and body awareness. For 24 weeks, 3 years old children (n=47) underwent a structured PE plan conducted by a PE teacher. The sessions included adequate motor coordination, overall coordination, spatial structure, temporal organisation, body structure, body image, body knowledge, and laterality. The control group (n=48) also had physical activity in the school playground, but it was not structured or conducted by a PE teacher. The results showed that ability scores were significantly higher than in the control group, for all measured abilities: Coordination and Balance, Body Scheme, Temporal Organisation, and Spatial Organisation (Costa et al., 2015).

Eleven of 14 studies found one or more positive associations between school-based PE and indicators of academic performance; three studies found no significant associations. Studies in the review examined increased physical education time (achieved by increasing the number of days physical education was provided each week or lengthening class time) and/or improved quality of physical education, e.g. trained instructors and increasing active time during PE class (Rasberrya et al., 2011).

In the Swedish Bunkeflo project Ericsson and Karlsson (2012) studied long-term effects on motor skills and school performance of increased PE and Health (PEH) over nine years. An intervention group (n=129) achieved daily PEH (5x45 minutes/week) and if needed one extra lesson (60 minutes/week) of adapted MUGI motor training. The control group (n=91) had PEH two lessons (90 minutes/week). Motor skills were evaluated by the MUGI observation checklist and school achievements by marks in Swedish, English, Mathematics, PEH and the proportion of pupils who qualified for upper secondary school. Both boys and girls improved significantly in motor skills and the differences between them decreased with extended PEH and extra motor training in school. In school year 9 there were no motor skills deficits in 93% of the pupils in the intervention group compared to 53% in the control group and 96% of the pupils in the intervention group compared to 89% in the control group qualified for upper secondary school. The difference was due to a group difference in boys (96% versus 83%), where the sum of evaluated marks was also higher in the intervention group than in the control group). The study clearly shows that increased PEH and adapted motor skills training conferred better motor skills as well as higher marks and higher proportion of pupils who reached qualification for upper secondary school.

Health-economic analyses of the Bunkeflo intervention (daily PEH and adapted MUGI motor skills training) show that daily PEH in all schools in the city of Malmö would increase the potential production value by SEK 59 million (€ 6.4 million) during a 10-year period after compulsory school. The higher levels of physical activity would reduce morbidity costs by SEK 56 million (€ 6 million). These values exceed the SEK 16 million (€ 1.2 million) that costs of staff and premises amount to. An investment per student of SEK 4,600 (€ 500) for all nine compulsory school years would give productivity gains and reduced morbidity costs of SEK 38,000 (€ 4,130) per student ten years after leaving school (Gerdtham, Ghatnekar, & Svensson, 2012). Promoting physical activity for adults has in addition been found to improve employee health and brain function and increase financial returns for the company (Ratey & Loehr, 2011).

Kalaja (2012) conducted a PE intervention study in Finland (n=446 students in grade 7) during 33 weeks which focused three FMS: locomotion, manipulation, and balance. The intervention group showed more positive development in these variables compared to the control group, and slightly increased in self-reported PA, whereas the control group's PA decreased. Girls scored higher in static balance and rope jumping tests, whereas boys scored higher in dynamic balance, leaping, accuracy throwing, and dribbling tests as well as in perceived PA competence and ego-involving motivational climate. Perceived PA competence was the only significant predictor of PA engagement. The results also showed that task-involving motivational climate was a strong predictor of perceived PA competence and self-determined motivation toward PE. The study demonstrated that in secondary school PE, there is a need to emphasize teaching of students' FMS. Improved skills might be one factor to prevent the typical decline of PA within adolescence.

According to Yli-Piiparia (2014) the Finnish education system has received worldwide attention due to the top academic performance of Finnish school students. PE potentially contributes to the overall success; the subject has a solid foundation in Finnish schools and strong support in Finnish society. Over the past decades, PE has been marginalized across the Western world and PE time in Finland has diminished across four decades. However, the education reform from 2012 allocate more time and funding for elementary and middle school PE by adding an annual weekly lesson for two years during grades 1–9. In addition, schools and PE teachers are required to implement a new criterion-referenced assessment and feedback program to evaluate students' fitness levels and to motivate students to participate in health-enhancing PA. This is in contrast to norm-referenced assessment, i.e. judging and grading the learning of students by comparing and *ranking* each student against the performance of other students in the same cohort.

School PE in Finland aims to enhance students' competency in motor skills and movement patterns, promote a physically active lifestyle and physical fitness, promote responsible personal and social behavior, promote appropriate values, and promote enjoyment of and self-expression in PA. At the basic education level (grades 1–9) the main emphasis is on learning a wide variety of motor skills. Although the national curriculum states the same PE objectives for girls and boys, 5th–9th grade curricula note that PE instruction must make allowances for the differing needs of boys and girls at this stage of development, as well as the students' differentials in growth and development generally. Since the 1970s, one of the most central purposes of schooling in Finland has been the holistic development of students; PE is an important piece in an academic education system that helps the nation to achieve the objectives of the 21st century (Yli-Piiparia, 2014).

Soares and Hallal (2015) found a strong negative correlation between students in Brazil having no PE and the proportion of active adolescents. Despite challenges in terms of infrastructure, lack of materials, low value of the discipline and low salaries of teachers as compared to those observed in other countries, the existence of more PE classes is related to higher physical activity levels among Brazilian youth.

Relationship between motor skills and cognition

Intellectual skills and perceptual-motor skills are psychologically more alike than different and they are acquired in fundamentally similar ways (Rosenbaum, Carlsson, & Gilmore, 2001). The timing of brain development and associated neuroplasticity for motor skill learning makes the preadolescence period a critical time to develop**,** reinforce and automatize FMS in boys and girls (Myer et al., 2015). Children who do not participate regularly in structured motor skill-enriched activities during PE classes or sports programs may never reach their genetic potential for motor skill control which underlies sustainable physical fitness later in life. Youth who are ill-prepared for play and sport have fewer opportunities for positive social interaction and are less likely to experience enjoyment of physical activity (Ericsson, 2008; Myer et al., 2015).

Morgan, Barnett, Cliff et al. (2013) included 22 articles in a systematic review and meta-analysis. All studies reported significant intervention effects for FMS. Meta-analyses revealed large effect sizes for overall gross motor proficiency and locomotor skill competency. A medium effect size for object control skill competency was observed. The author's conclusion is that school- and community-based programs that include developmentally appropriate FMS learning experiences, delivered by PE specialists or highly trained classroom teachers, significantly improve FMS in youth.

Cognition is grounded in perceptual-motor experiences within social and cultural contexts. Perceptual-motor behaviors can, according to Lobo, Harbourne, and Dusing (2013) facilitate future development and advance readiness to learn in school. Object interaction, sitting, and locomotor behaviors can be improved in infants and children by focusing on exploration, active trial and error hypothesis testing, variability of practice, high frequency of practice, and caregiver education and involvement. Self-exploration, problem solving, and active involvement in their own learning process are critical factors in children's motor skill development. Individual feedback and support from a teacher are important in this process (Westendorp, Houwen, Hartman et al., 2014).

Evidence indicates that motor competence (MC) is positively associated with perceived competence and multiple aspects of health (i.e., PA, cardiorespiratory fitness, muscular strength, muscular endurance, and healthy weight status). Children (11 years old) with low MC performed poorer on fitness tasks, were less physically active and had lower perception of athletic competence and social acceptance than children with high MC in a study conducted by Vedul-Kjelsås, Stensdotter, Sigmundsson and Haga (2015). Well-developed gross motor skills facilitate children's cognitive functioning (Westendorp, Hartman, Houwen et al., 2011) and higher levels of MC are associated with higher order cognitive function, working memory and processing speed. The strength of associations between MC and both cardiorespiratory endurance and muscular strength tends to increase from childhood into adolescence (Robinson, Stodde, Barnett et al., 2015). Effects of endurance and strength training before puberty are significantly lower than during and after puberty (Berg & Ekblom, 2015).

Son and Meisels (2001) included 12,583 children in US kindergartens and found that gross motor skills and visual motor skills were unique, significant predictors of first-grade reading and mathematics achievement; suggesting longitudinal relations between early motor skills and the skills in later cognitive achievement. Similar results were found by Ericsson and Karlsson (2012). These findings support the hypothesis that motor skills are related to later cognitive achievement and are able to successfully identify children at risk for academic underachievement later in school.

Westendorp et al. (2011) compared gross motor skills of 7- to 12-year-old children with learning disabilities (n=104) with those of typically developing children (n=104) using the Test of Gross Motor Development-2. Children with learning disabilities scored poorer on both locomotor and object-control than their typically developing peers. A specific relationship was found between reading and locomotor skills and between mathematics and object-control skills: the larger children's learning lag, the poorer their motor skill scores. The relationship between gross motor skills and cognitive performance appears to be specific rather than general. An intervention (n=45) of 16 weeks (40 minutes per week) of specific ball skill training was sufficient for improving ball skills (automatization of basic ball skills) in children with learning disabilities but no effects were found on any cognitive parameters (reading and mathematics) or EFs (problem solving or cognitive flexibility) compared to a control group (n= 46) (Westendorp et al. 2014).

Draper, Achmat, Forbes, and Lambert (2012) evaluated the Little Champs program for motor development on the gross motor skills and cognitive function of children (n=118). The children were exposed to play and opportunity to develop and master motor skills. The results showed that children exposed to eight months of Little Champs had significantly better overall scores for locomotor and object control skills compared to the control group. There was a statistically significant improvement in the cognitive scores of children who participated regularly in the program. The findings suggest that even limited exposure to a low intensity program for motor development can positively impact gross motor skills and cognitive function in disadvantaged preschoolers. The authors conclude that play and opportunity to develop and master fundamental motor skills form the foundation for the development of skills that can be used in sport later in childhood and adolescence. Participation in the program can also serve to enhance the social skills of participants and increase their levels of self-efficacy regarding motor skills (Draper et al., 2012).

Koutsandréou, Wegner, Niemann, and Budde (2016) examined the influence different types of exercise programs on primary school children's working memory. Participants (n = 71) were randomly assigned to a cardiovascular exercise (CE), a motor exercise (ME) or a control group. The intervention involved 10 weeks of additional afterschool exercise, 45 minutes three times a week. Students in the control group participated in assisted homework sessions. Working memory performance of the 9-10 year olds benefited from both the cardiovascular and motor exercise programs, but not from the control condition. The increase in working memory performance was significantly larger for children in the ME compared to the CE group. Special motor demanding interventions seem to be a beneficial strategy to improve working memory in preadolescent children.

Summary, Conclusions and Discussion

This study includes not only randomized controlled trials (RCT), but also school based interventions where perfectly matched control groups as well as randomization of individuals are hard to achieve. The lack of RCT in the area of PE and motor skills research, which is a limitation, makes it relevant to consider what impact findings in other scientific studies might have, e.g. quasi experimental or pre-post trials. However, conclusions derived from studies reviewed in this article must be drawn with cautiousness.

In summary research show that children with higher levels of motor competence have better inhibitory control, attention capacity and academic performance than children with poorer motor skills (Haapala, 2013). They also exhibit higher order cognitive function, working memory and processing speed. Motor skills training and regular PA has been found to enhance corticomotor development and academic performance in school age youth (Myer et al., 2015) and in a consensus conference 24 researchers conclude that mastery of FMS is beneficial to cognition and scholastic performance in children and youth (Bangsbo, Krustrup, Duda et al., 2016). It is, however unclear whether simple aerobic exercise (such as walking) without a cognitive component or motor skills training without an aerobic component, assists developing cognitive functions in growing children. Effects of motor skills training and muscle strength is not enough investigated for any conclusions to be drawn according to Berg and Ekblom (2015) and maybe aerobic training combined with motor skills training produces the best combination for cognitive development.

The school is the only arena where we can reach the vast majority of children and youth and public school curricula have the greatest promise for accessibility to all (Diamond & Lee, 2011; Ericsson, 2003; Ericsson & Karlsson, 2012). For many children and youths, school curricula are the only way they can receive physical activity on a daily basis. Daily PE in combination with adapted motor skills training during the compulsory school years has shown to be a feasible way to improve not only motor skills but also academic achievements and the proportion of pupils who qualify for upper secondary school (Ericsson & Karlsson, 2012). Research clearly shows that increased PE and adapted MUGI motor skills training can positively influence both higher grades and higher proportions of pupils who reach qualification for upper secondary school. In addition the investment can be health-economically profitable for the municipality (Gerdtham, Ghatnekar, & Svensson, 2013; Ratey & Loehr, 2011).

Educational benefits claimed for PE are however dependent on contextual and pedagogic variables. Type of activity and psychological factors could mediate associations between physical activity and scholastic performance. Enhancing enjoyable physical noncompetitive activities in the school curriculum may yield benefits in academic achievements and psychological health of children, particularly girls, according to Bunketorp Käll et al., 2015), and time taken away from lessons in favour of PE does not come at the cost of scholastic performance in children and youth (Bangsbo et al., 2016).

Motor assessment is associated with later school achievement and can be used as one of the indicators of future school achievement of young children. Motor performance can contribute to predict children's cognitive preparedness for school. Including motor skills in early school assessment may increase the probability of identifying children at risk for school failure (Ericsson, 2003, 2008a, 2008b; Ericsson & Karlsson, 2012; Son & Meisels, 2006). Motor skill screening provides a valuable tool for identifying children in need of adapted support in motor skill development (Bangsbo et al., 2016).

Specific interventions are needed for children with learning disabilities, programs that facilitate both motor and academic abilities (Ericsson & Karlsson, 2012; Westendorp et al., 2011). Two examples of models for motor skills acquisition are presented below.

Integrative Neuromuscular Training (INT)

Integrative Neuromuscular Training (INT) for youth focuses on integration of physical and cognitive training, i.e. to combine physical practice (FMS, core strength and control, agility and coordination, recovery, postural control, and muscular fitness) with cognitive training (social interaction, cognitive distraction, visual motor, neurocognitive, muscular relaxation, and stress management). INT early in life and maintained throughout adolescence will likely maximize one's potential to optimize motor skill abilities (optimal FMS), cortex structural, and cognitive development, and to engage regularly in physical activity (Myer et al., 2015).

The Motor Skills as Ground for Learning (MUGI) model

The Motor Skills as Ground for Learning model [in Swedish: Motorisk Utveckling som Grund för Inlärning (MUGI)] (Ericsson, 2003), influenced by social cognitive theory (Bandura, 1997) and used as an education program, includes motor skills screening of pupils at school start and offers of adapted motor skills training. The aim is to identify children with difficulties in motor skills in order to give early support and stimulate their motor skills development, before any motor deficits become a problem to the children. MUGI is based on the principle of success, i.e. the children are never asked to perform tasks they cannot do, but instead offered exercises with the aim of automatization of skills coming earlier in motor skills development. One of the most important goals is that children feel motivated and enjoy taking part in physical activities. It is important that focus is on what the child wants to learn, and that goals are achievable. The principles in MUGI motor training can be summarized as:

- Success instead of failure
- No training of skills the child cannot perform
- Automatization of skills in earlier development

With better, i.e. automatized fundamental motor skills, the child will hopefully improve in self-efficacy (Bandura, 1997), social abilities, and eventually also in self-esteem. An early evaluation of the MUGI model showed that the motor training in pre-school had positive effects school year 1 on children's motor control, perception and ability of remembering details (Ericsson, 2003).

Recommendations regarding physical activity for children and adolescents

Although physical activity might be beneficial at all stages of life, early interventions might be important for the improvement and/or maintenance of cognitive health and function throughout adult lifespans (Hillman et al., 2008). Based on the relationship between motor skills and cognition/scholastic performance the following can be recommended. For children and young people aged 5-17 years physical activity includes play, games, sports, transportation, recreation, physical education or planned exercise, in the context of family, school, and community activities. Children and young people should, according to WHO (2010), accumulate at least 60 minutes of moderate to vigorous-intensity physical activity daily. The activities should be as varied as possible to provide aerobic fitness, muscle strength, flexibility, speed, shorter reaction times and coordination (Berg, 2014). Activities should develop children physically, i.e. improve movement prerequisites, and game-play environment that is mentally engaging and providing joy is recommended (Diamond & Ling, 2016; Myer et al., 2015).

In order to improve motor skills and scholastic performance the following recommendations can be formulated:

1. Public school curricula have the greatest promise for accessibility to all (Diamond & Lee, 2011; Ericsson, 2003; Ericsson & Karlsson, 2012) and the National Association for Sport and Physical Education (NASPE) recommends daily PE (Centers for Disease Control and Prevention, 2010) in all schools. PE can be recommended as a core subject in compulsory school at least 40 min/day (Ericsson & Karlsson, 2012; Myer et al., 2015). Legislation changes require at least three PE classes per week for Brazilian youth (Soares & Hallal, 2015), and all EU member states are called upon to schedule the same amount for all school children (European Parliament, 2007).
2. Physical activities specifically focused to improve motor control in children and adolescents (Myer et al., 2015) are recommended. In secondary school PE there is a need to emphasize teaching of students' fundamental movement skills (FMS). Improved motor skills might be one factor to prevent the typical decline of PA within adolescence (Kalaja, 2012).
3. A varied/multisport approach to PE is recommended, coordinated and matched to ability and interest of students for best improvements in aerobic fitness, motor skills, task orientation and self-efficacy (Ericsson, 2003; Myer et al., 2015).
4. Integrative Neuromuscular Training (INT) can be recommended for improvements of FMS, as well as for cortex structural, and cognitive development (Myer et al., 2015), the training should be intermittent rather than continuous. A feasible tool in automatization of FMS can be the MUGI model (Motorisk Utveckling som Grund för Inlärning [Motor Skills as Ground for Learning]) model. Practice should build self-confidence and create feelings of belonging.
5. Pedagogical skills are needed in teaching motor skills. Age-appropriate instructions should be conducted by qualified PE teachers (Costa et al., 2015; Ericsson, 2008b; Myer et al., 2015). Pediatric skills are needed in identifying and treating children with exercise deficit disorder and development coordination disorder (DCD) (Ericsson, 2003, 2008a, 2008b; Myer et al., 2015). Specific attention to motor skills training in children with learning difficulties is necessary (Ericsson, 2003, 2008a; Westendorp et al., 2014). Specific 'adapted' interventions should be offered to children with motor skill deficits in order to benefit motor development and motivation for participation in physical activities (Bangsbo et al., 2016).

6. Motor skill screening provides a valuable tool for identifying children in need of adapted support in motor skill development (Bangsbo et al., 2016). Early identification of children with poor motor performance is recommended in order to improve their motor and academic skills during the first school years (Ericsson, 2003, 2008b; Haapala et al., 2014). Motor skill observations are recommended at school start to increase the predictability of later achievement and the probability of identifying children at risk for school failure (Son & Meisels, 2001). The MUGI checklist could be used as a pedagogical tool in conducting motor skills screening (Ericsson, 2003, 2008a, 2008b; Ericsson & Karlsson, 2012).

Challenges for future research

There is a need to synthesize the evidence regarding brain and motor control to provide a framework for a sustainable/life-long interest in physical activity. Future intervention studies specifically designed to test the dose-response relationship between cardiorespiratory training as well as motor skills training and cognition are needed. Physiological or psychological mechanisms that are impacted by physical activity participation, but not on changes in aerobic/cardiovascular fitness may be responsible for the benefits to cognitive performance (Etnier et al., 2006). The cognitive components of the physical activity might be the main contributors to any EF benefit.

Consensus regarding the concept Fundamental Movement Skills (FMS) is needed, as well as how to measure different parts of motor skills. Several important research questions still need to be examined, e.g. what are the best method for improving FMS and cognition? Are solitary or group activities best for motor skills acquisition? How important is it to include cognitive challenges into motor skills and aerobic training? Should focus be on improving balance, eye-hand, bimanual coordination and automatization of FMS? How important is pleasure and joy in movement?

In school-based interventions it is important to clearly separate effects of PE programs, from those of classroom activities or extended recess time. Robust studies, i.e. RCT, and meta-analyses are needed to provide evidence of the effectiveness of different PE programs (Yli-Piiparia, 2014) and motor skills interventions.

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