Chapter 1

Introduction

BACKGROUND

Sports play an important role in the current society. Sports may lead to more social cohesion (Van Hilvoorde, Elling, & Stokvis, 2010) and research shows that essential intra-individual characteristics and social skills could be developed through team sports, such as self-esteem, cooperating with peers and perseverance (see for a review, Eime, Young, Harvey, Charity, & Payne, 2013). However, research from many countries show a decrease of participation in organized sports, in particular in young age groups over the last decades (e.g. van Van Bottenburg, Rijnen, & Van Sterkenburg, 2005; Stamatakis & Chaudhury, 2008).

Not only participation in organized sports (structured and often competitive physical activity) decreases, involvement in regular physical activity declines as well. Only 21% of the children aged 4 to 11 years, and 13% of the children and adolescents aged 12 to 17 years in the Netherlands currently meet the international physical activity guidelines (TNO, 2013). The guidelines recommend 60 minutes of daily physical activity for children and adolescents, following findings on the minimum amount of physical activity necessary for enhancing health (Strong et al., 2005). More specifically, those 60 minutes of activity should be spent in moderate-to-vigorous physical activity (MVPA), which is defined as activity above three age-adjusted metabolic equivalents of tasks (METs). MET is considered a resting metabolic rate obtained during quiet sitting. Examples of METs above three are cycling, swimming and playing soccer (Ainsworth et al., 2000). Several systematic reviews and meta-analyses reported that in particular cardio-vascular and respiratory health, bone density and mental health (e.g. anxiety levels, mood) profit from physical exercise (Janssen & LeBlanc, 2010; Ekelund et al., 2012). Despite research recommending the opposite, schools schedule less time for activities such as active play (e.g. playing outdoor) and physical education (e.g. Hillman, Erickson, & Kramer, 2008). Outside school, children spend less time playing outdoor as compared to previous generations, partly due to unsafe environmental factors such as unsafe roads and playing grounds (Carver, Timperio, & Crawford, 2008).

At the low end of the physical activity continuum, sedentary behaviors become an increasing problem among youth (Tremblay et al., 2011). Sedentary behaviors are activities with low METs, such as watching TV and sitting (for instance at school or in a car). It has been shown that sedentary behaviors are independent of physical activity, indicating that it is not necessary that physical activities are replaced by sedentary behaviors. However, daily sedentary behavior among Dutch children is increasing (Hendriksen, Bernaards, Hildebrandt, & Hofstetter, 2013) and modern society invites for sedentary behaviors such as driving a car, using public transport and playing computer games (e.g. Biddle, Petrolini, & Pearson, 2003; Chillón, Evenson, Vaughn, & Ward, 2011). Research showed that sedentary behavior is associated with elevated risks for diabetes mellitus type II, obesity and cardiovascular diseases (Sisson et al., 2009; Owen, Healy, Matthews, & Dunstan, 2011; Martinez-Gomez, Tucker, Heelan, Welk, & Eisenmann, 2009). Both the decrease in physical activity, as well as the increase in sedentary behaviors may thus have a negative impact on public health.

PHYSICAL ACTIVITY AND NEUROCOGNITIVE FUNCTIONING

During the last decades, a growing body of studies suggested that people should adopt to a healthy and active lifestyle not only for the beneficial effects on physical health, but also because involvement in regular physical exercise is shown to benefit neurocognitive functioning. Neurocognitive functions are generally described as behavioral outcomes of brain processes including for example verbal and spatial memory, attention, (fine) motor skills, processing speed and inhibition (e.g. Tooze, Gittoes, Jones, & Toogood, 2009). Several reviews on healthy elderly reported a positive relationship between physical fitness and functions such as memory and processing speed (Kramer, Hahn, Cohen, Banich, McAuley, Harrison et al., 1999; Lautenslager & Almeida, 2006). Research in children shows that higher fit children outperform less fit peers on several neurocognitive functions such as inhibition (e.g. Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Chaddock et al., 2010). Also, studies revealed positive effects of physical activity on academic achievement (see for a review, Tomporowski, Davis, Miller, & Naglieri, 2008) and it is suggested that life-long participation in physical activity may delay cognitive decline at older age (see for a review, Bherer, Erickson, & Liu-Ambrose, 2013).

Several mechanisms have been proposed to explain the beneficial influence of physical activity on neurocognitive functioning.
Studies on the immediate (acute) effect of physical activity show that exercise increases cerebral blood flow (CBF) in arteries that are known to provide blood supply to large parts of the frontal, temporal and parietal lobes up to 39% (Hellström, Fisher-Colbrie, Wahlgren, & Jogestrand,1996; Sato & Sadamoto, 2010). These brain areas strongly relate to neurocognitive functions (e.g. Kolb & Wishaw, 2008) and it is argued that exercise temporarily boosts functioning of these areas. Furthermore, an immediate effect of exercise around the lactate threshold is associated with increased catecholamine (i.e. noradrenalin, adrenalin, dopamine) secretion in the peripheral blood. It has been suggested that this increase of peripheral catecholamine indirectly influences arousal in the central nervous system, enhancing neurocognitive performance (e.g. Chmura, Krysztofiak, Ziemba, Nazar, & Kaciuba-Uścilko, 1997; McMorris, Collard, Corbett, Dicks, & Swain, 2008).

Underlying a possible chronic beneficial effect of physical exercise on neurocognitieve functioning, a number of mechanisms have been suggested. The first is angiogenesis in the brain, which is the process of new (small) blood vessel formation or extension, improving the perfusion capacity of target tissues (Kleim, Cooper, & VandenBerg, 2002). A second possible underlying mechanism is neurogenesis, the process of new neuronal cell formation, which is restricted to three areas in the human brain, including the dentate gyrus of the hippocampus (Butz, Teuchert-Noodt, Grafen, & van Ooyen, 2008). It has been found that preadolescent children with higher cardiovascular fitness have larger volumes of the basal ganglia and hippocampus, which was associated with better performance on tasks for attentional functioning and memory (Chaddock et al., 2010). In addition, several neurotrophic factors might play an important mediating role in the effects of physical exercise on neurocognitive functions, among which are brain derived neurotrophic factor (BDNF), nerve growth factor (NGF), and insulin-like growth factor 1 (IGF-1), although evidence in humans is limited (e.g. Lu & Gottschalk, 2000; Ferris, Williams, & Shen, 2007; Floël, Ruscheweyth, Krüger, Willemer, Winter, Völker et al., 2010).

Irrespective of the well-described mechanisms to explain effects of physical activity on the brain, it remains unknown on which frequency and for how long one should exercise before it enhances neurocognitive functioning. It is also unclear how long the effect of acute exercise (e.g. a couple of hours) or chronic exercise (e.g. months) will last.

Moreover, a number of studies suggested that especially participating in organized sports may benefit neurocognitive functioning, because in these activities, more time is spent in MVPA as compared to playing outdoor or jogging (e.g. Wickel & Eisenman, 2007). However, up until now, no studies are performed to investigate whether possible differences in neurocognitive functioning are dependent on the amount of involvement in organized sport activities.

SEDENTARY BEHAVIOR AND NEUROCOGNITIVE FUNCTIONING

Concerning the relationship between sedentary behavior and neurocognitive functioning, most research has been conducted in elderly (e.g. Kesse-Guyot, Charreire, Adreeva, Touvier, Hercberg, Galan et al., 2012; Hamer & Stamatakis, 2014). Those studies show that in particular TV watching is negatively associated with neurocognitive functioning in healthy elderly. However, Kesse-Guyot and colleagues (2012) reported that not all sedentary behavior may have adverse effects on neurocognitive functions: Elderly who increasingly used their computer at older age showed better visual memory as compared to healthy elderly who decrease time spent on the computer. Research on children is limited, but a review of LeBlanc and colleagues (2012) reported on eight studies that investigated the relationship between TV watching and neurocognitive development in infants, toddlers and preschoolers. It was concluded that TV watching has a negative dose-response relationship with neurocognitive development (i.e. 'babbling' and language development) in young children, although results must be interpreted with caution because the studies were of low-quality. Importantly however, sedentary behavior is associated with obesity and studies show that obesity may lead to decreased neurocognitive functioning, as has been shown in studies on adults as well as in children (see for a review, Smith et al., 2011).

NEUROCOGNITIVE FUNCTIONING IN ATHLETES

The desire for effective talent identification already has a long history. Typically, training in a particular sport always increases skills to some degree. However, such training also uncovers variation among people in their improvement over time: Not everyone becomes an elite athlete or champion (Tucker and Collins, 2012). To understand such variation in the effectiveness of training, it is interesting to obtain knowledge about the possible underlying capacities in talented athletes that makes them an elite athlete on the long-term. For example, abundant studies have been performed on measuring sprint performance and endurance capacity in young athletes, as well as evaluating body height, mass and growth in young children in order to predict capabilities for a particular sport (e.g. Reilly, Bangsbo, & Franks, 2000; Elferink-Gemser, Visscher, Van Duijn, & Lemmink, 2006; Sherar, Baxter-Jones, Faulkner, & Russell, 2007). However, although some anthropometrical and physiological characteristics are required for some sports (e.g. being tall for competing at the top basketball level), it is shown that those measures do not predict performance in the future. For example, a review on the predictive value of physiological tests in soccer showed that physiological characteristics did not predict which athlete made it to the adult elite level (Pearson, Naughton, & Torode, 2006).

Given the absence of physiological predictors, it may be valuable to also investigate other aspects of athletic performance, for example neurocognitive functioning. Similar to general athletic skills such as 30-meter sprint and endurance capacity, neurocognitive functions may be a prerequisite for performance in many sports such as soccer, field hockey, basketball, volleyball and rugby. In these sports, the environment changes fast due to opponents, ball movements, teammates and changing tactics. Consequently, fast adaptations in terms of planned movements, attentional focus, pattern recall and decision making are essential in order to perform well. In the last decades, a growing body of literature shows that elite athletes outperform non-elite athletes on some neurocognitive functions that are required for their specific sport. For instance, studies show that elite athletes outperform lower level peers on basic visual perception, visual search and quiet eye movements (see for a review, Mann, Williams, Ward, & Janelle, 2007). In several studies, sport-specific experiments were conducted such as using videotapes of soccer situations, in which soccer players from diverse competition levels had to make decisions based on specific situations (e.g. Vaeyens, Lenoir, Williams, & Phillipaerts, 2007). These types of studies are valuable to investigate whether experience (in terms of practice hours) in a particular sport may lead to enhanced performance on perceptual or neurocognitive tasks in particular sport-related situations but it could be questioned whether these type of tasks measure underlying capabilities of athletes.

The present thesis investigates neurocognitive functions such as attention, motor inhibition, visuospatial memory and motor learning in highly talented youth athletes and amateur athletes to elucidate possible underlying capacities for superior performance on tasks underlying sport-specific skills, by using non-sport specific tasks with control conditions such as simple reaction time tasks or baseline conditions, as well as speed and difficulty manipulations.

AIMS

This thesis has two main aims. The first (Chapters 2-3) is to further explore the relationship between physical activity and neurocognitive functioning in children. Especially the influence of organized sports is investigated, by comparing preadolescent children varying on the frequency and intensity in which they participate in organized sports. Also, possible dose-response relationships between physical activity, sedentary behavior and neurocognitive functioning will be explored. The second aim (Chapters 4-6) is to investigate non-sport specific neurocognitive functions in highly talented youth athletes as compared to less talented peers to elucidate possible underlying capacities for superior performance on tasks underlying sport-specific skills.

SAMPLE AND STUDY DESIGN

Using a cross-sectional design, three groups of participants were compared. First, children (aged 7 to 12 years, n=51) who were not involved in any organized sports activities were included (Chapter 3 and 4). Participants of this group were recruited at several elementary schools in Amsterdam (the Netherlands) and the geographical area around Amsterdam. Children were included when they did not participate in any organized sports, such as soccer or regular extra-curricular sport activities at school. A second group consisted of amateur soccer players (aged 7 to 12 years, n=70), recruited at two amateur soccer clubs in Amsterdam: SV de Meer (Chapters 3-5) and SC Buitenveldert (Chapter 6). The third group of participants were elite soccer players (aged 7 to 12 years of age, n=125), recruited from three youth academies of Dutch premier league soccer clubs: AFC Ajax (Chapter 3-5), Vitesse, and FC Utrecht (Chapter 6).

Test administration of the participants of SV de Meer and AFC Ajax took place between February 2011 and December 2012. Test administration of the group of children who did not participate in sports was between December 2012 and December 2013. For participants of SC Buitenveldert, FC Utrecht and Vitesse, test administration was between April 2013 and December 2013.

THESIS OUTLINE

This thesis is divided into two parts. **Part A** (Chapter 2-3) focuses on the first aim of the thesis: the relationship between physical activity and neurocognitive functioning in children. In Chapter 2, the effects of physical exercise on executive functioning in children, adolescents and young adults are examined in a comprehensive meta-analysis. Randomized controlled trials and studies using cross-over designs on the effects of acute (a single session) and chronic (regular) exercise are included. Results are discussed in light of diverse executive functioning domains, age groups and limitations, and future directions are provided. In Chapter 3, the focus is on organized sports by comparing children who are not involved in organized sports, children who are regularly involved in organized sports (amateur soccer players) and children who are very frequently involved in sports (elite soccer players) on a broad battery of neurocognitive tasks assessing motor inhibition, verbal and visuospatial working memory, attentional networks and processing speed to study the role of participation in sports on neurocognitive functioning. Also, dose-response relationships between physical activity, sedentary behavior and neurocognitive functions are examined.

Part B (Chapter 4-6) focuses on the second aim of this thesis: investigating neurocognitive functioning in highly talented youth athletes as compared to less talented peers to elucidate possible underlying capacities for superior performance on neurocognitive tasks. In Chapter 4, youth elite soccer players, youth amateur soccer players and children who are not involved in organized sports are compared on a newly developed visuomotor coordination task. Of specific interest is visuomotor performance of the elite soccer players in unpredictable situations, which may be crucial for performance in soccer at the highest level. In Chapter 5, focus is on executive functioning, including motor inhibition, attentional networks, and visuospatial working memory in youth elite soccer players and amateur soccer players to study possible superior functioning in highly talented athletes as compared to lower-level peers. Executive functions might be important for successful performance in sports, particularly in team sports requiring quick anticipation and adaptation to continuously changing situations in the field. In Chapter 6, youth elite and amateur soccer players are compared to investigate explicit and implicit motor learning in youth elite soccer players. In this chapter, explicit and implicit motor learning are assessed in parallel. It is hypothesized that the highly talented elite soccer players learn faster as compared to the amateur soccer players. At the end of the thesis (Chapter 7), a summary and discussion of the findings can be found. The discussion combines results of all chapters, critically evaluates and integrates the findings and proposes new avenues for future research.

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