

Chapter 3

Physical Activity, Sedentary Behavior and Neurocognitive Functioning in Children

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ABSTRACT

Purpose Evidence has shown a positive relationship between physical activity and neurocognitive functioning. Aim of the present study is to investigate whether differences in neurocognitive functioning between children depend on the amount of involvement in organized sport activities and to investigate the relationship between sedentary behavior and neurocognitive functioning.

Method We compared groups of preadolescent children (aged 8-12) varying in the amount of participation in organized sports: children not participating in organized sports (sedentary children), children regularly participating in sports (amateur soccer players), and children very frequently participating in sports (elite soccer players). Groups were compared on motor inhibition, working memory, three attentional networks, and processing speed. Multivariate regression analyses examined the predictive power of physical activity and sedentary behavior for neurocognitive functioning and exploratory mediation analyses were performed to investigate indirect effects on the found relationships.

Results Sedentary children performed poorer than elite soccer players on motor inhibition, and three working memory components; they also showed poorer Tau (lapses of attention) than both soccer player groups. No group differences were found for the attentional networks and processing speed. Regression analyses showed that time spent on physical activity predicted better functioning of the central executive components of working memory, whereas sedentary behavior was found to predict worse visuospatial sketchpad functioning. Tau mediated the relationships between groups and neurocognitive functions.

Conclusions The present study showed that children who are not involved in organized sports have poorer motor inhibition, working memory scores and more lapses of attention. This is highly relevant given the relationship between those neurocognitive functions and academic achievement. Interventions are required to increase sports activities in preadolescent children in order to benefit neurocognitive functioning.

INTRODUCTION

The beneficial health effects of physical exercise seem generally well-known (for a review, see Strong, Malina, Blimkie, Daniels, Dishman, Gutin et al., 2005). Yet most children and adolescents have not reached a healthy standard of exercise. According to research, 21% of the children up to 11 years of age, and 13% of the adolescents between 12 and 17 years of age, meet the recommended 60 minutes of daily moderate-to-vigorous physical activity (MVPA) (TNO, 2013). MVPA is defined as activity above three age-adjusted metabolic equivalents (METs), which are for example jogging, swimming or playing soccer (Ainsworth, Haskell, Whitt, et al., 2000). Research showed that 60 minutes MVPA per day is the minimum amount to benefit the cardiovascular system and muscular health in youth (Strong et al., 2005). Importantly, ample evidence uncovered a positive association between physical activity and neurocognitive functioning (e.g. Chaddock, Pontifex, Hillman, & Kramer, 2011; Verburgh, Königs, Scherder, & Oosterlaan, 2014a). Studies on the relationship between regular physical exercise and neurocognitive functioning in children showed that higher fit children outperform their lower fit peers on neurocognitive functions such as memory and processing speed (Chaddock et al., 2011). A recent meta-analysis revealed that short bouts of physical exercise (e.g. 30 minutes) have positive effects on executive functioning in youth of all ages (Verburgh et al., 2014a). Executive functions are higher-order neurocognitive processes that underlie reasoning, planning and problem solving (Diamond, 2013), all essential for functioning in daily life. Numerous studies show that executive functions are positively and strongly related to intelligence and academic achievement (Bull, Espy, & Wiebe, 2008).

Physical activity during organized sports is strongly associated with MVPA (Silva, Andersen, Aires, Mota, Oliveira, & Ribeiro, 2013). Notably, it has been shown that physical education (PE) lessons at school do not seem to contribute much to MVPA: A study that analyzed the amount of MVPA (by using accelerometers) during a regular PE class showed that only 11.9 minutes were spent in MVPA (Nader, 2003). Furthermore, it was shown that active play (outdoor playing without structure or rules) contributed significantly to total physical activity in school-aged children, but was only associated with daily MVPA in girls (Brockman, Jago, & Fox, 2010). Voluntary participation in youth

sports organized at school contributed on average 23% to daily MVPA, with soccer yielding the highest contribution (30%) of the sports studied (Wickel & Eisenmann, 2007; Guagliano, Rosenkranz, & Kolt, 2013). Hence, participation in organized sports activities seem to contribute most to MVPA in children and it is suggested that the recommended daily 60 minutes of MVPA is not achieved on a day without organized youth sports (Wickel & Eisenmann, 2007).

Recent studies show that there is an increase in sedentary behaviors among children and adolescents (see for a review, Pate, Mitchell, Byun, & Dowda, 2011). Sedentary behaviors are activities such as TV-watching, playing computer games and driving to school instead of walking or cycling (Biddle et al., 2004). Those behaviors are found to be independent of the daily physical activities. For example, watching TV does not necessarily displace active behaviors such as sports training (Biddle, 2004). A growing body of research showed that sedentary behavior might contribute to the worldwide increase in overweight, type 2 diabetes and metabolic problems (e.g. elevated cholesterol levels) (Steele, van Sluijs, Cassidy, Griffin, & Ekelund, 2009). Importantly, it has been shown that overweight is negatively associated with neurocognitive functions in children and adults (Smith, Hay, Campbell, & Trollor, 2011). However, no study to date has investigated the relationship between sedentary behavior and neurocognitive functioning in children (Voss, Carr, Clarck, & Weng, 2014).

The present study addressed the relationship between both physical activity and sedentary behavior, and neurocognitive functioning by comparing three groups of preadolescent children varying in the amount of physical activity and sedentary behavior: children who do not participate in any organized sports, children regularly participating in sports, and children very frequently participating in sports. Given the strong relationship between participation in organized sport activities and MVPA, we also investigated whether differences in neurocognitive functioning between children are dependent on the amount of involvement in organized sport activities. A broad battery of tests was used to assess core neurocognitive functions including motor inhibition, verbal working memory, visuospatial working memory, attention and processing speed.

METHODS

PARTICIPANTS

A total of 168 children between 8 and 12 years of age participated in the study: one group of 51 boys not involved in organized sports (sedentary group, mean age = 10.4 ± 1.4), one group of 48 boys regularly participating in sports (amateur soccer players, mean age = 10.5 ± 1.3), and a third group of 69 boys very frequently participating in sports (elite soccer players, mean age = 10.6 ± 1.4). All participants lived in the geographical area around Amsterdam. Participants of the sedentary group were not involved in any organized sports activities (i.e. were neither member of a sports club, nor participating in an extracurricular sports program at school) and were recruited at elementary schools. The amateur players were recruited from an amateur soccer club. The elite players were recruited from the youth academy of a Dutch professional soccer club and were following the talent development program of the youth academy. Players at this youth academy have been selected by scouts on basis of several qualities (subjectively rated using broad criteria) such as technique, athletic skills and tactics (for more details on the soccer groups and Dutch soccer system, see Verburgh et al., 2014b). The current study extended the study by Verburgh et al. (2014b) by adding additional neurocognitive measures, increasing sample sizes and adding a group of sedentary children. Participants were free of known behavioral, learning and medical conditions that might impact neurocognitive functioning and were excluded when they had an $IQ < 70$ as measured by a short version of the Wechsler Intelligence Scale for Children III (Wechsler, 1997). Demographics of the groups are displayed in table 1.

MATERIALS

MOTOR INHIBITION

The Stop Signal task (Logan, 1994) was used to measure motor inhibition. The task involved go trials and stop trials. Go trials consisted of a drawing of an airplane presented in the center of the computer screen either pointing to the right or to the left and requiring a spatially compatible response on one of two response devices. A fixation point preceded the go stimulus. Stop trials were identical to go trials, but in addition a stop signal (a white cross

superimposed on the airplane) was presented subsequent to the onset of the airplane. Participants were instructed not to press either of the two buttons, when they saw the stop signal. The stop signal was presented after onset of the airplane presentation with an initial delay of 175 ms, lengthened by 50 ms if the response was inhibited successfully, and shortened by 50 ms if the participant failed to inhibit the response. This resulted in an average success rate around 50% on stop trials. The task consisted of two practice blocks and three experimental blocks. The first practice block consisted of 32 only go trials. The second practice block consisted of 32 trials including 25% stop trials. Experimental blocks consisted of 64 trials and also included 25% stop trials. The dependent variable that reflects the latency of the inhibitory process is stop signal reaction time (SSRT). SSRT was calculated by subtracting average stop signal delay time from mean reaction time (MRT) calculated for correct responses on go trials. Shorter SSRTs reflect a faster and more efficient inhibitory process. Additional dependent variables derived from the Stop Signal task were MRT as a measure of reaction time and the percentage of errors (commission and omission) on go trials as a measure of accuracy.

WORKING MEMORY

Three aspects of working memory were assessed: The phonological loop, the visuospatial sketchpad, and the central executive (Baddeley, 2012). The phonological loop and the verbal component of the central executive were measured using the Digit Span task of the WISC III (Wechsler, 1997). Participants were asked to verbally reproduce series of digits that increased in length (difficulty level). In the first condition, participants were required to repeat the series in a forward order, thereafter, the series of numbers were asked to be repeated in a backward order. In both conditions, two trials were administered for each difficulty level and the condition was ended when a subject failed on two trials of the same difficulty level. For both conditions, the total number of correct responses multiplied by highest difficulty level passed was included in the analyses (Kessels, van zandvoort, Postma, Kappelle, & de Haan, 2000), with the total score of the forward condition as a measure of phonological loop functioning and the total score of the backwards condition as the verbal measure of the central executive.

The visuospatial sketchpad and the visuospatial component of central executive were measured using an adapted version of the task developed by Bergman-Nutley, Söderqvist, Bryde, Humphreys, & Klingberg, 2009). Participants were asked to reproduce a sequence of yellow circles that was presented in a 4 x 4 grid on a computer screen. First, participants were required to repeat the sequence (using the computer mouse) in a forward order. In the second condition, participants were required to repeat the sequence in a backward order. Difficulty level was increased during the course of the task by increasing the span and by manipulating the position of the stimuli after every two trials. Two trials were administered for each difficulty level, and the condition was terminated when the participant failed to accomplish both trials of the same difficulty level. For both conditions, the total number of correct responses multiplied by highest sub level passed was calculated (Kessels et al., 2000). The total score of the forward condition was included as a measure of the visuospatial sketchpad and the total score of the backwards condition as a measure of the visuospatial component of the central executive.

ATTENTION

Three aspects of attention were assessed: alerting, orienting and executive attention. A modified version of the Attention Network Test (ANT) (Fan, McCandliss, Sommer, Raz, & Posner, 2002) was used to measure alerting and orienting attention. Participants were instructed to respond as quickly and accurately as possible by pressing either the left or the right response button corresponding to the side of the computer screen where a soccer goal appeared (target stimulus). There were three types of trials: Neutral trials consisted of a target stimulus presented at either the left or right side of the computer screen. Alerting trials and orienting trials were similar to the neutral trials in terms of the target stimulus. However, in alerting trials a neutral cue (a ball) was presented in the center of the screen preceding the target stimulus and in orienting trials a spatial cue (a referee pointing in the direction where the target would appear) preceded the target stimulus. The task consisted of one practice block and three experimental blocks. The first block consisted of 24 practice trials. Experimental blocks consisted of 48 trials each.

To assess executive attention, participants completed a modified version of the Flanker task (Eriksen & Eriksen, 1974). The target stimulus was a black arrow

against a white background, presented in the center of a computer screen, pointing either to the left or right. This target was flanked on either side by two black arrows pointing in the same direction (congruent trials), in the opposite direction (incongruent trials), or by black horizontal lines (neutral trials). Participants were required to respond as quickly and accurately as possible to the target by pressing either the left or right button corresponding to the direction the target was pointing to. The task consisted of one practice block with 12 trials and two experimental blocks of 36 trials.

The relative change between MRT of correct alerting trials and MRT of correct neutral trials was used to assess alerting attention. The relative change between MRT on correct spatial trials and MRT on correct alerting trials was used as a measure of the ability to direct attention (orienting attention) and the relative change between MRT of correct congruent trials and MRT of incongruent trials from the Flanker task was used as a measure of the ability to actively ignore irrelevant information (executive attention). For alerting and orienting attention, a larger relative change between trial types indicates better performance, for executive attention, a smaller difference between trial types indicates better performance. Furthermore, accuracy measures of alerting, orienting and executive attention were included as dependent variables.

PROCESSING SPEED

Consistency in speed of information processing was examined using the individual response time distributions derived from correct go trials of the Stop Signal task. Each participant executed 145 go trials, which allows reliable analyses of processing speed (LaCouture & Cousineau, 2008). The ex-Gaussian distribution model, as described by Lacouture and Cousineau combines a normal distribution shape of individual reaction times with an exponential component on the right side of the distribution. With this model, μ is calculated to determine the average speed of processing corrected for extreme slow responses. Furthermore, σ (fluctuations in speed of processing) and τ (proportion of extreme slow responses, measuring lapses of attention) were calculated (Whelan, 2008).

FULL-SCALE IQ ESTIMATION

Full-scale IQ was estimated by the Wechsler Intelligence Scale for Children

III (Wechsler, 1997). Two subtests (Vocabulary and Block Design) were administered, which each correlate $>.90$ with full-scale IQ (Groth-Marnat, 2001).

PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOR ESTIMATION

Involvement in physical activities and sedentary behavior were assessed using a physical activity questionnaire (TNO, 2007). This questionnaire consists of 13 questions on physical activity (e.g., 'How many days a week are you going to school walking or cycling?') and seven on sedentary behavior (e.g., 'How many day a week do you watch television?'). Participants were required to indicate how many days per week and how many minutes per day they participated in each of the activities listed. Adequate reliability and validity have been reported for the questionnaire and dependent variables derived from this questionnaire are presented in total minutes per week spent on a physical activity and sedentary behavior (TNO, 2007).

PROCEDURE

Data of the elite soccer players and amateur soccer players were collected at the soccer club during the competitive soccer season. Test administration took place before soccer training. Data of the sedentary group were collected at elementary schools during regular school hours or immediately after school. There were two sessions with a duration of approximately one hour for each individual participant. All participants were tested in a quiet room and the tasks were administered in the same order for each participant by trained assessors using standardized instructions. First, body height and body weight were measured to calculate body mass index (BMI), followed by the WISC III and the neurocognitive tasks. The study was approved by the local ethical committee of the Institutional Review Board of the VU University Amsterdam. All participants and parents and/or legal guardians were informed about the procedures of the study before giving their written informed consent prior to participation.

STATISTICAL ANALYSES

SPSS version 22.0 was used for all statistical analyses (SPSS IBM, New York, U.S.A). Participants not attending the second test session, technical difficulties or not speaking fluent Dutch resulted in missing data for some tasks. When individual dependent variables were missing, participants were excluded from

further analyses ($n=3$ in the sedentary group, $n=2$ in the amateur soccer player group). Total missing data of demographic variables was less than 5% ($n=6$ for IQ, $n=8$ for the questionnaire on physical activity and sedentary behavior in the elite soccer player group) and were replaced by expectation maximalization (Tabachnick & Fidell, 2001). Dependent measures derived from neurocognitive function measures were converted into z-scores using a Van der Waerden transformation (Tabachnick & Fidell, 2001). First, possible group differences in physical activity, sedentary behavior, BMI and IQ were tested using univariate analyses of variance (ANOVA). Significant group effects were further explored with Tukey post hoc comparisons. Pearson correlations across groups were performed to determine associations between demographic variables and dependent measures and when significant, entered as covariates in subsequent analyses.

Next, the dependent variables derived from the neurocognitive function measures were subjected to separate univariate analyses of variance (ANOVA) with group as between subjects factor (three levels: sedentary children, amateur soccer players, and elite soccer players). If a significant effect of group emerged, Tukey post hoc comparisons controlling overall alpha level ($p < .05$) were conducted to further study group differences. In order to examine the predictive power of physical activity and sedentary behavior for neurocognitive functioning, two separate multivariate multiple regression analyses were conducted. The dependent variables derived from the neurocognitive tasks were included as dependent variables. Age and BMI may correlate with the neurocognitive measures and were therefore included as covariates (Smith et al., 2011).

RESULTS

DEMOGRAPHICAL RESULTS

Group characteristics are shown in table 1. Total minutes of physical activity and sedentary behaviors per week were not significantly correlated ($r = -.08$, $p = .31$). Also, there were no significant relationships between the demographic variables (as presented in table 1) and neurocognitive measures, with one exception: as expected, IQ significantly correlated with measures of working memory ($.25 > r < .30$, $p < .01$). However, considering the substantial overlap between IQ and working memory and the debate on using IQ as covariate when groups differ

(Miller and Chapman, 2009), IQ was not included as covariate in subsequent analyses. Table 2 presents the group differences for the neurocognitive measures examined in this research.

MOTOR INHIBITION

A main effect of group was found for SSRT and post hoc comparisons showed poorer motor inhibition in the amateur soccer players and sedentary group as compared to the elite soccer players, with no significant difference between the sedentary group and amateur soccer players. No evidence for speed-accuracy tradeoff was found: The Pearson correlation between MRT and percentage of errors was $r=.09$, $p=.27$, indicating that findings for MRT and errors may be interpreted independently. A trend was found for MRT, but post hoc comparisons showed no significant differences among the groups. For percentage of errors, a main effect of group was found and post hoc comparisons showed that elite soccer players made less errors as compared to the sedentary group and amateur soccer players, again with no difference in performance between the sedentary group and amateur soccer players.

WORKING MEMORY

On the forward condition of the verbal working memory measure, a trend was found for group. Post hoc comparisons showed that the sedentary group performed worse than the elite soccer players, indicating poorer functioning of the phonological loop in sedentary children, but better functioning in elite soccer players. Mean scores of the amateur soccer players lay in between the two other groups and did not significantly differ. On the backward condition, a main effect of group was found, and post hoc comparisons showed that both elite and amateur soccer players outperformed the sedentary group, with no significant difference between the soccer player groups. This indicated poorer functioning of the verbal central executive component of working memory in children not involved in organized sports.

For visuospatial working memory, a main effect of group was found on the forward condition. Post hoc analyses showed poorer performance of the sedentary group as compared to the elite soccer players, again with no significant difference between the sedentary group and amateur soccer players. These results indicate poorer functioning of the visuospatial sketchpad in

children not participating in sports. No significant group differences were found for the backward condition.

ATTENTION

No significant main effect of group on all three networks was found. This indicates that when there was an alerting or an orienting cue, groups showed comparable decreases in MRT. Also, similar increases in MRT were found across groups when incongruent information surrounded the target as compared to when congruent information was presented surround the target. Likewise, no difference between groups was found on accuracy of the networks (table 2).

PROCESSING SPEED

Significant main effects of group were found for Sigma and Tau and a trend was found for Mu. Post hoc comparisons on Mu showed that there was no meaningful difference in processing speed between groups. Elite soccer players showed somewhat more variable responses as compared to amateur soccer players, with no significant difference between the sedentary group and amateur soccer players. Both soccer player groups outperformed the sedentary group on Tau, with no significant difference between the soccer player groups. This indicates that children who are not involved in organized sports show more lapses of attention.

REGRESSION ANALYSES

Physical Activity

The multivariate regression analysis with physical activity as predictor, age and BMI as covariates, and the neurocognitive measures that discriminated between groups as dependent variables revealed a multivariate main effect ($F(10,158)=3.6, p<.001$). Analyses showed that total time spent in physical activity predicted scores on Digit Span backward and the backward condition of the visuospatial working memory task. For the Digit Span backward, BMI did not contribute significantly to the model ($F(2,166)=1.6, p=.61$), but age explained 10% of the variance ($R^2=0.10; F(2, 166)=18.2, p<.001$). Physical activity added another 6% of explained variance to the model ($R^2=0.06, F(1, 167)=11.2, p<.001$) to predict Digit Span backward of the visuospatial working memory task (standardized Beta=.25, $t=3.36, p<.001$). For the backward condition of

the visuospatial working memory task, BMI did not contribute significantly to the model ($F(2,166)=.83, p=.57$), but age explained 14% of the variance ($R^2=0.14$; $F(2, 166)=26.3, p<.001$), whereas physical activity added another 6% of explained variance to the model ($R^2=0.06, F(1, 167)= 1.9, p<.001$, standardized Beta=.25, $t=3.5, p<.001$). These results indicate that children who spent more time in physical exercise show higher scores on the central executive components working memory.

Sedentary Behavior

The multivariate regression analysis with sedentary behavior as predictor also revealed a multivariate main effect ($F(10,158)=1.9, p<.05$). Of the possible covariates, age significantly contributed to the model, explaining 13% of the variance in the backward condition of the visuospatial working memory task ($R^2=0.13$; $F(2, 166) = 23.9, p<.001$). Sedentary behavior added another 3% of explained variance to the model ($R^2=0.03, F(1, 167)=5.0, p<.05$, standardized Beta =-.17, $t=-2.4, p<.05$). Furthermore, sedentary behavior predicted SSRT: of the possible covariates, age significantly contributed to the model, explaining 11% of the variance in SSRT ($R^2 = 0.11$; $F(2, 166)=18.6, p<.001$), whereas sedentary behavior added 4% explained variance ($R^2=0.04, F(1, 167)=6.2, p=.01$) to predict SSRT (standardized Beta= - 1.99, $t=-2.5, p=.01$). These results indicate that children who spend more time in sedentary behavior show poorer scores the phonological component of working memory and motor inhibition.

EXPLORATORY MEDIATION ANALYSES

As has been shown in recent research on attention deficit/hyperactivity disorder (ADHD), Tau might be related to frontal brain circuits, executive functions and white matter integrity (Lin et al., 2013). Therefore, post hoc exploratory mediation analyses were conducted to examine whether the relationship between group and dependent variables was mediated by Tau. These analyses were conducted using the PROCESS macro for SPSS of Hayes (2012).

Separate mediation analyses were performed for the dependent variables discriminating between groups: SSRT, percentage errors on the Stop Signal task, the Digit Span forward and backward and the forward condition of the visuospatial working memory task. Tau was included as mediator. Results revealed a complete mediation effect of Tau on the relationship between group

and the phonological loop (point estimate = -0.07 , SE = 0.32 , 95% confidence intervals [CI] = -1.41 , -0.03), the forward condition of the visuospatial working memory task (point estimate = -0.11 , SE = 0.04 , 95% CI = -0.20 , -0.04) and percentage of errors (point estimate = -0.11 , SE = 0.04 , 95% confidence intervals = -0.21 , -0.05 , $p < 0.01$). The direct relationship between group and these dependent variables became non-significant. The relationship between group and the Digit Span backward and SSRT was only partly mediated by Tau (point estimate = -0.04 , SE = 0.03 , 95% CI = -0.11 , -0.004 and point estimate = -0.08 , SE = 0.04 , 95% CI = -0.17 , -0.02 , respectively).

Table 1. Group characteristics

	Sedentary Children (N=51) Mean (SD)	Amateur Soccer Players (N=48) Mean (SD)	Elite Soccer Players (N=69) Mean (SD)	Test Statistic	p-value	Post hoc Tukey ($p < .05$)
Age	10.4 (1.2)	10.5 (1.3)	10.6 (1.4)	F(2,165)=.23	.79	
Handedness (% right handed)	84.1	81.6	88.4	$\chi^2=1.1$.58	
IQ	101.7 (14.9)	101.8 (15.5)	92.3 (10.7)	F(2,165)=9.7	<.001	EP<AP=SC
BMI	17.9 (3.1)	17.1 (2.5)	17.6 (.45)	F(2,165)=.1.3	.18	
Underweight (%)	4.5	12.2	100%			
Healthy (%)	75	77.6				
Overweight (%)	20.5	10.2				
<i>Physical activity</i>						
Total (minutes/week)	780.3 (403.6)	1246.4 (434.8)	1077 (365.1)		.001	AP>EP>SC
Transport (minutes/week) ^a	96.8 (670)	111.2 (88.6)	126.3 (92.6)	F(2,165)=1.7	.18	
Physical education (minutes/week)	95.1 (30.3)	86.5 (39.8)	88.7 (57.8)	F(2,165)=.43	.65	
Outdoor play (minutes/week)	588.4 (381)	813.2 (392)	470.9 (298.1)	F(2,165)=13.7	<.001	AP>SC
Sports (minutes/week)	0	253.5 (100)	391 (49.1)	F(2,165)=524.2	<.001	EP>AP
<i>Sedentary behavior*</i>						
Total (minutes/week)	1003.5 (579.1)	859.3 (439.8)	800 (579.1)		<.001	EP<SC
TV watching (minutes/week)	587.3 (402.8)	484.2 (362)	349.2 (229.8)	F(2,165)=7.5	<.001	EP<AP=SC
Computer (minutes/week) ^b	416.2 (480.1)	375.1 (270.8)	450.8 (450.8)	F(2,165)=0.8	.45	
Active gaming (minutes/week) ^c	58.9 (109.9)	80.1 (131.8)	77.9 (98.1)	F(2,165)=.49	.61	

Note: SC=sedentary children; AP=amateur soccer players; EP= elite soccer players; IQ=intelligent quotient; BMI=body mass index

^aActively walking or cycling to school; ^bUsing computer, internet, playing games or at game console (e.g. Playstation, Nintendo); ^cPlaying active games on the computer or game console (e.g. Wii Sports).

Table 2. Group differences on neurocognitive measures

	Sedentary Children (N=51) Mean (SD)	Amateur Soccer Players (N=48) Mean (SD)	Elite Soccer Players (N=69) Mean (SD)	Test Statistic	p-value	Partial Eta ²	Post hoc Tukey (p<.05)
<i>Motor inhibition</i>							
SSRT	270.8 (70.5)	280.6 (65.9)	227.6 (41.5)	F(2,165)=12.5	<.001	.14	EP>AP=SC
MRT of go trials	538.9 (90.9)	504.7 (81)	532.7 (116.5)	F(2,165)=2.9	.06	.04	AP>SC
% errors on go trials	3.0 (2.0)	3.8 (2.8)	1.9 (1.7)	F(2,165)=10.6	<.001	.12	EP>AP=SC
<i>Verbal working memory</i>							
Forward condition	39.6 (14.1)	44.7 (18.2)	46.7 (16.9)	F(2,165)=2.6	.08	.03	EP>SC
Backward condition	17.0 (8.9)	27.3 (16.2)	25.4 (25.4)	F(2,165)=10.6	<.001	.11	EP=AP>SC
<i>Visuospatial working memory</i>							
Forward condition	66.2 (27.5)	69.3 (30.5)	75.9 (23.3)	F(2,165)=3.2	<.05	.04	EP>SC
Backward condition	52.9 (28.3)	58.1 (34.4)	60.4 (28.4)	F(2,165)=1.3	.27	.02	
<i>Attentional Networks</i>							
Alerting	26.5 (5.9)	27.1 (6.8)	26.2 (7.5)	F(2,165)=.67	.51		
Orienting	4.8 (7.9)	6.0 (7.9)	6.8 (7.1)	F(2,165)=1.6	.20		
Executive	12.3 (10.6)	14.6 (8.3)	15.7 (6.7)	F(2,165)=2.4	.10		
% errors Alerting	3.8 (2.5)	4.6 (3.9)	4.0 (3.5)	F(2,165)=.82	.44		
% errors Orienting	3.5 (2.3)	4.4 (3.3)	3.7 (3.8)	F(2,165)=1.1	.34		
% errors Executive	6.5 (7.2)	10.5 (12.3)	7.3 (6.7)	F(2,165)=2.7	.08		
<i>Processing speed</i>							
Mu	423.8 (68.1)	395.5 (57.9)	429.8 (103.2)	F(2,165)=2.5	.09	.03	
Sigma	69.9 (30.6)	60.1 (19.8)	78.7 (44.6)	F(2,165)=3.9	<.05	.05	EP<AP
Tau	135.3 (44)	112 (34.5)	98.5 (42.4)	F(2,165)=11.1	<.001	.13	EP=AP>SC

Note: SC=sedentary children; AP=amateur soccer players; EP= elite soccer players; MRT= mean reaction time; SSRT=stop signal reaction time. See main text for an explanation on how the measures were calculated.

DISCUSSION

The present study addressed the relationship between both physical activity and sedentary behavior and neurocognitive functioning by comparing three groups of preadolescent children varying in the amount of physical activity and sedentary behavior: children who do not participate in any organized sports, children regularly participating in sports, and children very frequently participating in sports. Results of the neurocognitive measures showed that the sedentary children have poorer scores on motor inhibition, made more errors on the Stop Signal task and show poorer working memory than the elite soccer players; moreover, they exhibit more lapses of attention (Tau) as compared to both groups of children participating in sports. Regression analyses found a positive dose-response relationship between physical activity and the central executive components of working memory and a negative dose-response relationship between physical activity and the phonological component of working memory and motor inhibition. Furthermore, a mediating role of Tau on neurocognitive functioning was found

As expected based on our selection procedure, groups clearly differed in the time spent in sports with sedentary children spending no time on sports, amateur soccer players spending 253 minutes/week and elite soccer players spending 391 minutes/week on sports. The children classified as being sedentary in the present study indeed showed more sedentary behavior (i.e. TV watching) than the children who participate in organized sports. Group characteristics also showed that sedentary children and elite soccer players played less outdoor as compared to amateur soccer players. Findings in elite soccer players may be explained by the many hours of soccer training they participate in, which allows less time to play outdoor during leisure time.

Results of the Stop Signal task showed that the sedentary children and the amateur soccer players have poorer scores on motor inhibition and made more errors on go trials as compared to the elite soccer players. These findings were supported by the regression analysis showing a negative dose-response relationship between sedentary behavior and motor inhibition, indicating that more sedentary behavior may lead to poorer motor inhibitory skills. Our findings are highly relevant in light of the worldwide increase of sedentary behavior among youth (Voss et al., 2014) and the importance of inhibitory control for

academic achievement (Bull et al., 2008). Because there were no group differences between amateur soccer players and sedentary children on motor inhibition, it might be suggested that motor inhibition as measured by SSRT might not be a sensitive measure for discriminating between groups differing on time spent in physical activity, but does discriminate highly talented athletes from amateur athletes, as was shown in Verburgh et al. (2014b).

Regarding working memory, it was found that the sedentary children performed poorer than the elite soccer players on tasks appealing to both the phonological loop, the verbal central executive component and the visuospatial sketchpad. Performance of amateur soccer players was in between the performance of sedentary children and elite soccer players and was only significantly better than the sedentary group on the verbal central executive component. These findings were supported by our regression analysis, showing a positive dose-response relationship between physical activity and both central executive components of working memory, enhancing the likelihood of a causal relationship between physical activity and abilities to manipulate verbal and visuospatial information.

No group differences were found on all three attentional networks, indicating that the groups respond similarly to alerting, orienting and executive cues (e.g. faster responses when a spatial cue was presented as compared to a neutral cue), resulting in comparable relative gain in MRT with each of the three cues. Also, no group differences in percentage or errors were found. Findings on the executive network of attention are in line with a study by Hillman and colleagues (2009), reporting no improvement on executive attention, but only an effect of improved accuracy on the Eriksen Flanker task following a short exercise bout. All groups in our study performed very well in terms of accuracy, and therefore the lack of significant differences may be due to a ceiling effect on this task. This is supported by results of Drollette, Scudder, Raine et al. (2014), showing that children performing in the lower ranges of the Eriksen Flanker task improved on accuracy after a short bout of exercise, whereas the higher performing children did not improve.

No significant group differences were found for Mu, but the elite soccer players showed a larger Sigma than the amateur soccer players, indicating somewhat more fluctuations in response speed during the Stop Signal task. This may be explained by the different strategy used by the two groups when performing

the task, as was described by Verburgh et al. (2014b). Importantly, sedentary children were found to show a larger proportion of extreme slow responses (Tau) as compared to both groups of children participating in sports. Exploratory post hoc mediation analyses showed that the relationships between group and percentage of errors on the Stop Signal task, the phonological loop and visuospatial sketchpad were fully mediated by Tau. This suggests a crucial role of Tau when performing neurocognitive tasks, signifying that suffering from lapses of attention may lead to more errors and poorer performance in terms of performance on aspects of working memory and reaction time. Furthermore, Tau only partly mediated the relationship between group and motor inhibition and the central executive component of verbal working memory, suggesting that these functions may be more complex than the completely mediated neurocognitive functions. Interestingly, physical fitness is associated with increased white matter integrity in the frontal brain areas in adults (Voss, Heo, Prakash, Erickson, Alves, Chaddock, et al., 2009) and it has been shown that white matter integrity in the prefrontal cortex is positively associated with Tau (Lin, Gau, Huang-Gu, Shang, Wu, & Tseng, 2013). Thus, it may be speculated that physical exercise might improve neurocognitive functions through enhancement of Tau.

It should however be noted that the present study is limited by a correlational rather than experimental design, and no conclusions about causality may be drawn. Encouraged by dose-response relationships observed between both physical exercise and sedentary behavior and neurocognitive functions, there is high need of randomized controlled trials including sedentary children participating in an exercise program. A second limitation of our study is that measures of physical activity and sedentary behavior were based on self-report. However, self-report measures have been shown to provide valid measures of time spent in sedentary behaviors. For example, a review by Pate et al. (2009) reported that studies using self-reports, for example, to assess screen time in youth, showed similar average screen time as compared to studies using accelerometers to assess screen time.

The present study has several important implications. Findings on the poorer working memory scores of the sedentary children are highly relevant given the importance of working memory for academic achievement (Bull et al., 2008). For example, it has been shown that working memory can predict reading and

spelling achievement (e.g. Nevo & Breznitz, 2011). Likewise, results on Tau show that sedentary children suffer from more lapses of attention, which may lead to educational problems. For instance, visual sustained attention is related to mathematical skills (Anobile, Stievano, & Burr, 2013) and current results provide evidence for an important role of Tau in tasks performance.

Furthermore, sedentary children watched more TV than the other two groups and together with the time spent on games, they exceed the recommended two hours of screen time per day for this age group (Tremblay, LeBlanc, Janssen, Kho, Hicks, Murumets, et al., 2011). Because in this group, the lack of time spent on organized sports is not replaced by other physical activities, such as playing outdoor, physical exercise is a promising method to benefit neurocognitive functions, that in turn are crucial for academic performance. Children should be encouraged to become member of a sports club because being member of a sports club is associated with lifelong higher levels of psychical activity (Jekauc, Reimers, Wagnern, & Woll, 2013). Another way to enhance the total amount of MVPA is encouraging extracurricular sports activities at school (Beets, Beighle, Erwin & Huberty, 2009), active transport (instead of using the car) and playing outdoors (Carver, Timperio, Hesketh, & Crawford, 2010). Notably, a recent systematic review showed that sport club membership and team sport in particular is also associated with social health: children participating in team sports have better emotional control, conflict resolving and relationships with others (Eime, Young, Harvey, Charity, & Payne, 2013).

In conclusion, in line with previous research, results of the current study suggest a positive relationship between the involvement in sports and neurocognitive functions. Also, an important mediating role of Tau on neurocognitive functioning is suggested and this is the first study to date to demonstrate the detrimental impact of sedentary behavior on neurocognitive outcomes. Interventions are required to increase sport membership in preadolescent children in order to benefit neurocognitive functioning, physical health, and social health.

REFERENCES

- Ainsworth, B. E., Haskell, W. L., Whitt, M. C., Irwin, M. L., Swartz, A. M., Strath, S. J., . . . Emplaincourt, P. O. (2000). Compendium of physical activities: an update of activity codes and MET intensities. *Medicine and Science in Sports and Exercise*, 32(9; SUPP/1), S498-S504.
- Anobile, G., Stievano, P., & Burr, D. C. (2013). Visual sustained attention and numerosity sensitivity correlate with math achievement in children. *Journal of Experimental Child Psychology*, 116(2), 380-391.
- Baddeley, A. (2012). Working memory: theories, models, and controversies. *Annual Review of Psychology*, 63, 1-29.
- Beets, M. W., Beighle, A., Erwin, H. E., & Huberty, J. L. (2009). After-school program impact on physical activity and fitness: a meta-analysis. *American Journal of Preventive Medicine*, 36(6), 527-537.
- Bergman-Nutley, S. B., Söderqvist, S., Bryde, S., Humphreys, K., & Klingberg, T. (2009). Measuring working memory capacity with greater precision in the lower capacity ranges. *Developmental neuropsychology*, 35(1), 81-95.
- Biddle, S. J., Gorely, T., Marshall, S. J., Murdey, I., & Cameron, N. (2004). Physical activity and sedentary behaviours in youth: issues and controversies. *The Journal of the Royal Society for the Promotion of Health*, 124(1), 29-33.
- Brockman, R., Jago, R., & Fox, K. R. (2010). The contribution of active play to the physical activity of primary school children. *Preventive Medicine*, 51(2), 144-147.
- Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental neuropsychology*, 33(3), 205-228.
- Carver, A., Timperio, A., Hesketh, K., & Crawford, D. (2010). Are children and adolescents less active if parents restrict their physical activity and active transport due to perceived risk? *Social Science and Medicine*, 70(11), 1799-1805.
- Chaddock, L., Pontifex, M. B., Hillman, C. H., & Kramer, A. F. (2011). A review of the relation of aerobic fitness and physical activity to brain structure and function in children. *Journal of the International Neuropsychological Society*, 17(06), 975-985.
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64, 135-168.
- Drollette, E. S., Scudder, M. R., Raine, L. B., Moore, R. D., Saliba, B. J., Pontifex, M. B., & Hillman, C. H. (2014). Acute exercise facilitates brain function and cognition in children who need it most: an ERP study of individual differences in inhibitory control capacity. *Developmental cognitive neuroscience*, 7, 53-64.
- Eime, R. M., Young, J. A., Harvey, J. T., Charity, M. J., & Payne, W. R. (2013). A systematic review of the psychological and social benefits of participation in sport for children and adolescents: informing development of a conceptual model of health through sport. *International Journal of Behavioral Nutrition and Physical Activity*, 10(98).

- Eriksen, B. A. & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics*, 16(1), 143-149.
- Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*, 14(3), 340-347.
- Groth-Marnat, G. (2001). The Wechsler intelligence scales. Specific Learning disabilities and difficulties in children and adolescent. *Psychological assessment and evaluation*, 29-51.
- Guagliano, J. M., Rosenkranz, R. R., & Kolt, G. S. (2013). Girls' physical activity levels during organized sports in Australia. *Medicine and Science in Sports and Exercise*, 45(1), 116-122.
- Hayes, A. F. (2012). PROCESS: A versatile computational tool for observed variable mediation, moderation, and conditional process modeling. Retrieved from <http://www.afhayes.com/public/process2012.pdf> Website access date 2014 June 24.
- Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience*, 159(3), 1044-1054.
- Kessels, R. P., van Zandvoort, M. J., Postma, A., Kappelle, L. J., & de Haan, E. H. (2000). The Corsi block-tapping task: standardization and normative data. *Applied Neuropsychology*, 7(4), 252-258.
- Lacouture, Y. & Cousineau, D. (2008). How to use MATLAB to fit the ex-Gaussian and other probability functions to a distribution of response times. *Tutorials in Quantitative Methods for Psychology*, 4(1), 35-45.
- Lin, H.-Y., Gau, S.-F., Huang-Gu, S., Shang, C.-Y., Wu, Y.-H., & Tseng, W.-Y. (2013). Neural substrates of behavioral variability in attention deficit hyperactivity disorder: based on ex-Gaussian reaction time distribution and diffusion spectrum imaging tractography. *Psychological Medicine*, 1-14.
- Logan, G. D. (1994). On the ability to inhibit thought and action: A theory of an act of control. *Psychol Rev.* 1994: 91(3): 295-327.
- Miller, G. A. & Chapman, J. P. (2001). Misunderstanding analysis of covariance. *Journal of Abnormal Psychology*, 110(1), 40.
- Must, A. & Tybor, D. (2005). Physical activity and sedentary behavior: a review of longitudinal studies of weight and adiposity in youth. *International Journal of Obesity*, 29, S84-S96.
- Nader, P. R. (2003). Frequency and intensity of activity of third-grade children in physical education. *Archives of Pediatrics and Adolescent Medicine*, 157(2), 185-190.
- Nevo, E. & Breznitz, Z. (2011). Assessment of working memory components at 6 years of age as predictors of reading achievements a year later. *Journal of Experimental Child Psychology*, 109(1), 73-90.
- Pate, R. R., Mitchell, J. A., Byun, W., & Dowda, M. (2011). Sedentary behaviour in youth. *British Journal of Sports Medicine*, 45(11), 906-913.

- Silva, G., Andersen, L. B., Aires, L., Mota, J., Oliveira, J., & Ribeiro, J. C. (2013). Associations between sports participation, levels of moderate to vigorous physical activity and cardiorespiratory fitness in children and adolescents. *Journal of Sports Sciences*, 31(12), 1359-1367.
- Smith, E., Hay, P., Campbell, L., & Trollor, J. (2011). A review of the association between obesity and cognitive function across the lifespan: implications for novel approaches to prevention and treatment. *Obesity Reviews*, 12(9), 740-755.
- Steele, R. M., van Sluijs, E. M., Cassidy, A., Griffin, S. J., & Ekelund, U. (2009). Targeting sedentary time or moderate-and vigorous-intensity activity: independent relations with adiposity in a population-based sample of 10-y-old British children. *The American journal of clinical nutrition*, 90(5), 1185-1192.
- Strong, W. B., Malina, R. M., Blimkie, C. J., Daniels, S. R., Dishman, R. K., Gutin, B., . . . Pivarnik, J. M. (2005). Evidence based physical activity for school-age youth. *The Journal of pediatrics*, 146(6), 732-737.
- Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics* (4th ed.). Needham Heights, MA: Allyn & Bacon, 62-71.
- TNO (2007). Retrieved from: https://www.tno.nl/downloads/TNO-KvL_Rapport_Consensus_Vragenlijst_Sport_Bewegen.pdf. Website access date 2014 June 24.
- TNO (2013). Retrieved from: http://www.convenantgezondgewicht.nl/download/195/tno_monitor_convenant_gezond_gewicht_2013.pdf. Website access date 2014 June 24.
- Tremblay, M. S., LeBlanc, A. G., Janssen, I., Kho, M. E., Hicks, A., Murumets, K., . . . Duggan, M. (2011). Canadian sedentary behaviour guidelines for children and youth. *Applied Physiology, Nutrition, and Metabolism*, 36(1), 59-64.
- Verburgh, L., Königs, M., Scherder, E. J., & Oosterlaan, J. (2014a). Physical exercise and executive functions in preadolescent children, adolescents and young adults: a meta-analysis. *British Journal of Sports Medicine*, 48(12), 973-979.
- Verburgh, L., Scherder, E. J., van Lange, P. A., & Oosterlaan, J. (2014b). Executive functioning in highly talented soccer players. *PLoS ONE*, 9(3), e91254.
- Voss, M. W., Carr, L. J., Clark, R., & Weng, T. (2014). Revenge of the "sit" II: Does lifestyle impact neuronal and cognitive health through distinct mechanisms associated with sedentary behavior and physical activity? *Mental Health and Physical Activity*.
- Voss, M. W., Heo, S., Prakash, R. S., Erickson, K. I., Alves, H., Chaddock, L., . . . White, S. M. (2013). The influence of aerobic fitness on cerebral white matter integrity and cognitive function in older adults: Results of a one-year exercise intervention. *Human Brain Mapping*, 34(11), 2972-2985.
- Wechsler, D. (1997). *Wechsler Preschool and Primary Scale of intelligence third edition*: San Antonio, TX: Harcourt Assessment, Inc.

Whelan, R. (2008). Effective Analysis of Reaction Time Data. *Psychological Record*, 58(3), 475-482.

Wickel, E. E. & Eisenmann, J. C. (2007). Contribution of youth sport to total daily physical activity among 6-to 12-yr-old boys. *Medicine and Science in Sports and Exercise*, 39(9), 1493-1500.