Physical Fitness, Physical Activity, and the Executive Function in Children with Overweight and Obesity

Fitness and cognition in obese children

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Abstract

Objective: To examine the associations of physical fitness and physical activity (PA) with executive function in overweight and obese children.

Study design: A cross-sectional study involved 100 overweight and obese children (10.1 ± 1.1 years old; 58.0% boys). We assessed physical fitness components (i.e., muscular strength, speed-agility and cardiorespiratory fitness, CRF) using the ALPHA battery, and PA, and sedentary time by accelerometry. Cognitive flexibility was measured by Design Fluency Test and Trail Making Test; inhibition by Stroop test; and Planning ability the Zoo Map Test.

Results: Handgrip strength was positively associated with planning ability ($p=0.025$). Speed-agility was positively related to cognitive flexibility and inhibition ($p<0.05$). CRF and a Z-score of overall fitness were positively associated with indicators of cognitive flexibility ($p<0.05$). No associations were found for PA and sedentary time with executive function ($p\geq0.05$).

Conclusions: Muscular strength, speed agility, and CRF are associated with executive function in overweight and obese children. Cognitive flexibility seems to be more robustly associated with all fitness components, whereas planning ability and inhibition might depend on the component analyzed. The positive associations found in the present study in overweight/obese children call for more exercise-based randomized controlled trials in this population.

Key words: brain; aerobic fitness; executive control; cognitive control; cognitive performance; health; youth.

Abbreviations:

BMI Body mass index

CRF Cardiorespiratory fitness

MVPA Moderate-to-vigorous physical activity

PA Physical activity

SRT Shuttle-run test

1. Introduction

Physical fitness and physical activity (PA) have been shown as markers of children's physical health.[1,2] However, evidence on the relationship with cognition is still emerging.[3] Among all aspects of cognition, executive function appears to be the most closely linked function to physical fitness and PA.[3] Executive function is composed of cognitive flexibility, inhibitory control, planning, working memory, and decision making, which are particularly important for the performance of daily activities, for motor development, and for social relationships.[4] A recent systematic review supported a beneficial relationship between physical fitness or PA and the executive function in children.[3] In general, normal-weight children with higher levels of any fitness component have shown better performance in several executive functions, such as working memory, inhibition or cognitive flexibility.[3,5] As the vast majority of the present literature has focused on normal-weight children, the potential associations between physical fitness, PA, and the executive function are less known in overweight and obese children.

Obesity has been associated with detectable structural brain abnormalities during childhood, specifically with reductions in brain regions that underlie aspects of executive functioning.[6] A recent review suggested that PA-based programs improve the executive function in the obese young population.[7] High levels of physical fitness and PA may serve to counteract the negative influence of overweight and obesity on brain and cognition.[8]

The aims of the present study were i) to examine the association of each physical fitness component (i.e., muscular strength, speed-agility, and CRF) and an overall fitness score with indicators of the executive function (i.e., cognitive flexibility, inhibition, and planning ability) and ii) to examine the association of objectively measured PA and sedentary time with indicators of executive function in overweight and obese children. Given previous research, we hypothesize that physical fitness components, an overall fitness score, PA and sedentary time would relate to indicators of executive function.

2. Methods

The present cross-sectional study was conducted under the framework of the ActiveBrains project (http://profith.ugr.es/activebrains).[9] An initial sample of 110 overweight and obese Spanish children aged 8–11 years old were recruited from Granada, Spain after meeting the defined inclusion criteria: 1) overweight or obese based on World Obesity Federation cut-off points 2) to be 8 to 11 years-old, 3) no physical disabilities or neurological disorder, 4) for girls, not to have started the menstruation at the moment of the assessments, and 5) to be right-handed.[9] Recruitment was done at the Unit of Paediatrics of the University Hospitals San Cecilio and Virgen de las Nieves of Granada (Spain). Additionally, the head teacher of both public and private schools of Granada were contacted and advertisements in the local media were published. Any child meeting the inclusion criteria indicated above was invited to participate. The study was conducted in 3 waves of participation. For the present study, a sample of 100 overweight and obese children (10.1 ± 1.1 years old; 58.0% boys; 91% participation rate) was included with complete baseline data on physical fitness and executive function variables. For PA and sedentary time variables, we additionally excluded 4 participants since they did not have accelerometer data (n=96). The baseline data collection took part from November 2014 to February 2016. The ActiveBrains project was approved by the Human Research Ethics Committee of the University of Granada, and it was registered in ClinicalTrials.gov (identifier: NCT02295072).

Body weight (kg) was measured with an electronic scale (SECA 861, Hamburg, Germany), while height (cm) was measured using a precision stadiometer (SECA 225, Hamburg, Germany), both were measured twice and the average score was computed. We calculated the body mass index (BMI) (kg/m^2), and we defined BMI categories (i.e. overweight, obesity grade I, II, III) according to Cole & Lobstein.[10]

The ALPHA health-related physical fitness test battery for children and adolescents was used to assess physical fitness. A detailed description of the validity and reliability of the ALPHA battery has been provided elsewhere.[11] Briefly, muscular strength was assessed using the maximum handgrip strength test and the standing long jump test. In the handgrip test, each child performed the test twice with each hand, and the maximum value of each hand was taken and averaged. In the standing long jump test, the longest attempt from three was recorded (cm) and multiplied by the body weight to obtain an absolute measurement as in previous research in obese children.[12] The speed-agility was assessed twice using the 4×10-meter shuttle-run test (4×10m SRT) and the fastest completion time (sec) was recorded and inverted by multiplying by −1. CRF was assessed through the 20-meter shuttle-run test (20m SRT) and the total number of completed laps was registered.

The Z-score of muscular strength was calculated as the mean of the two standardized-by-sex scores (Z-standardized value = (absolute value – the sample mean)/SD) of the absolute handgrip strength and standing long jump tests. An overall physical fitness Z-score was then calculated as the mean of the standardized scores of each physical fitness component.

PA and sedentary time were assessed by accelerometer (GT3X+, ActiGraph, Pensacola, FL, USA). Information about the PA data processing criteria is shown in **Appendix 1**. In brief, children wore two accelerometers located on the non-dominant wrist and right hip simultaneously for 7 consecutive days (24h). For the present study, the data from the non-dominant wrist were used in order to be consistent with some major projects, such as the NHANES (https://www.cdc.gov/nchs/nhanes/index.htm), but analyses were replicated using the hip data (data not shown). The variables included in this study were total minutes per day at MVPA, sedentary time, and minutes accumulated in sustained bouts of 1, 5, and 10 minutes of MVPA with a drop tolerance of the 20% of the time.

Executive function was assessed for the domains of cognitive flexibility, inhibition, and planning ability. Cognitive flexibility and inhibition were assessed through different tests from the nine sub-scales of the Delis–Kaplan Executive Function System (D–KEFS).[13] All the tests were given to the participants by 3 different examiners and always in the same order. All the examiners were trained previously to the beginning of the study to perform the test in a coordinated matter and to be able to provide the same standardize instructions. This battery has a test–retest reliability ranging from 0.62 to 0.80.[14] Planning ability was assessed using the Zoo Map Test from the Behavioural Assessment of Dysexecutive Syndrome (BADS).[15] A full description of the tests and the protocols followed to obtained the final outcomes for each test are provided in **Appendix 2**. Briefly, the Design Fluency Test and the Trail Making Test were used as indicators of cognitive flexibility. For the Design Fluency Test, the total number of correct drawn designs from all 3 conditions was registered. For the Trail Making Test, we used the subtraction of the total completion time of Trail Making Test-A (Condition 2) from the total completion time of Trail Making Test-B (Condition 4). We inverted the B-A difference by multiplying this score by -1, so that a higher score indicated better cognitive flexibility. The individual score of each cognitive flexibility test was standardized by sex as follows: Z-standardized value = (absolute value – the sample mean)/SD. A cognitive flexibility Z-score was, therefore, calculated as the mean of standardized scores of Design Fluency Test and Trail Making Test. We used a modified version of the Stroop test to assess inhibition.[16] For the present study, we computed an interference score that was obtained by subtracting condition 3 completion time - condition 1 completion time. We also inverted this score by multiplying it by -1, so that higher scores indicated better inhibition. Finally, from the Zoo Map Test (i.e., planning ability),[15] the total sequence score was calculated as the sum of the sequence scores of conditions 1 and 2 (i.e. up to 16 points).

Sex, age, puberty stage, wave of participation, parental educational level, and the intelligence quotient were used as potential confounders in the analyses. Puberty stage was assessed by a physical examinaton carried out by a medical doctor and based on sexual maturation status (i.e., Tanner stages I-III).[17] The wave of participation was a categorical variable describing which wave of the study (1, 2, or 3) the child participated in. The parental educational level was assessed by a self-report questionnaire completed by the mother and father, and we combined the responses and classified them as: none of them had a university degree (coded as 1); one of them had a university degree (coded as 2); or both of them had a university degree (coded as 3).[18] The intelligence quotient of the participants was measured by the Spanish version of the Kaufman Brief Intelligence Test (K-BIT).[19]

The characteristics of the study sample are presented as means and standard deviations (SD) or percentages. Prior to all analyses, all outcomes were checked for normal distribution. Interaction analyses were performed between sex and BMI, physical fitness components, PA, and sedentary time on the executive function indicators. No significant interactions with sex or BMI were observed (all $p \geq 0.10$); therefore, the analyses were performed for all the participants together. We performed linear regression analyses to examine the association of each physical fitness component and an overall physical fitness score with executive function indicators adjusting by sex, age, puberty stage, wave of participation (entered as dummy variables), parental educational level, and intelligence quotient. We also performed linear regression analyses to examine the association of PA (i.e. MVPA, and bouts of MVPA) and sedentary time with the executive function indicators adjusting for the previous confounders. Each predictor was analyzed in a separate regression model for each dependent variable adjusting by all confounders.

A significance level of $p<0.05$ was set. Additionally, all analyses were corrected for multiple comparisons using the Benjamini-Hochberg method.[20] All the statistical procedures were performed using the SPSS software for Windows (version 22.0, IBM Corporation).

3. Results

Table 1 presents the descriptive characteristics of the study sample and by sex as means and standard deviations, unless otherwise indicated. **Table 2** shows the associations of each physical fitness component with indicators of executive function, adjusted for potential confounders. Handgrip strength showed a significant association with planning ability ($p=0.025$). Speed-agility was positively associated with cognitive flexibility assessed by the Design Fluency Test as well as with inhibition ($p\leq0.021$). Finally, CRF was significantly related to cognitive flexibility, specifically with the Design Fluency Test and the Trail Making Test ($p\leq0.033$). No associations were found for standing long jump or the muscular strength score with any of the executive function indicators ($p>0.05$).

Figure 1 presents the association between overall physical fitness and indicators of executive function, adjusting for potential confounders. Overall physical fitness showed a significant association with both parameters of cognitive flexibility, namely the Design Fluency Test and the Trail Making Test ($p\leq0.029$). No significant associations were found for inhibition and planning ability ($p>0.05$). After correcting for multiple comparisons, speed-agility, CRF, and the overall physical fitness remained significantly related to cognitive flexibility (i.e., Design Fluency Test), and speed-agility also to inhibition (all $p<0.05$).

No significant associations were found between PA, sedentary time and any of the executive function indicators ($p>0.05$) **(Table 3)**. Consistent results were obtained when performing the same analyses with hip-placement PA and sedentary time (data not shown).

4. Discussion

The main findings of the present study indicate that speed-agility, CRF, and an overall physical fitness score were positively related to cognitive flexibility. Particularly, CRF and the overall fitness score were related to both indicators of cognitive flexibility (i.e., Design Fluency Test and Trail Making Test). In addition, speed-agility was the only fitness component positively associated with inhibition, and muscular strength was the only component related to planning ability.

Previous studies have mainly focused on normal-weight or overweight children, and either on only one physical fitness component (i.e. CRF)[21,22] or on self-reported PA,[23] and the results of the present study are, generally, in line with the findings of these investigations. For cognitive flexibility, one of the studies showed that higher levels of CRF were related to higher cognitive flexibility toward the correct target during a color-shape switch task in overweight children.[22] Another study, also in overweight children, found that measures of peak VO_2 and treadmill time were positively associated to planning and attention scores.[21] In normal-weight children and adolescents, there are many studies supporting our associations between CRF and cognitive flexibility. For example, those with higher fitness levels (i.e., CRF) had a superior capability to flexibly allocate cognitive control processes.[24–27] Our findings can be also reconciled by previous randomized controlled trials in overweight and obese children which found dose-response benefits of an exercise program for physical fitness, executive function, and for areas of the brain that manage executive function.[21,28,29] We also found a positive relationship between speed-agility and cognitive flexibility, which concurs with a study showing a statistically significant association between different motor skills and cognitive flexibility already in normal-weight children.[30] Taking into account that cognitive flexibility is regulated by the prefrontal cortex, the anterior cingulate cortex, and the basal ganglia, the consistent positive findings between physical fitness and cognitive flexibility may be explained by the fact that increased levels of fitness are beneficial for these neural regions.[31]

With regard to inhibition, we found a positive association between speed-agility and the interference score in the Stroop test. A recent systematic review showed that complex motor skills are strongly related to higher-order cognitive skills such as inhibition.[32] Motor skills, such as the ones required for a proper performance in the speed-agility test used in the present study, involve precise execution movements based on an elaborated coordination of processes of motor movement. Thus, our findings may be explained by the fact that motor skills may activate a neuronal network that connects brain regions associated with both motor and cognitive functions.[33]

Regarding planning ability, we also found a positive association between handgrip strength and planning ability. However, this finding should be interpreted with caution since after correcting for multiple comparisons the significant association disappeared. To the best of our knowledge, there is no evidence concerning muscular strength and planning ability, which hampers comparisons with other studies.

This investigation also utilized an overall approach to quantify physical fitness (i.e., an integration of every fitness component in a composite score) when analyzing its relationship with the executive function. Consistent with this approach, a recent study reported a significant association between an overall score of physical fitness and the executive function measured in its three dimensions.[34] This is in agreement with our findings in the present study, and highlights the importance of being physically fit in all fitness components, since it is related to better cognitive flexibility.

While research on the association between physical fitness and the executive function in children have consistently delivered overall positive results,[3] findings regarding PA, sedentary time, and executive function are more inconsistent. Contrary to the existing literature,[23] we did not find any significant association between PA and the executive function. However, our non-significant associations are in line with previous studies showing that PA is not necessarily associated with all domains of executive function in normal-weight children.[35] The inconsistency between our non-associations of PA and sedentary time with executive function and the beneficial results of existing trials on cognition can be explained by previous literature declaring that cross-sectional associations do not necessarily indicate that the improvement of an outcome, such as MVPA, will result in improvements in outcomes previously associated with it (i.e., executive function).[21,36]

The main limitation of the present study was its cross-sectional design, which prevents from drawing causal associations. Another limitation may be the lack of some unmeasured social factors such as the family income that may be influencing both fitness and executive function.

The results of the present study suggest that not only CRF, but also muscular strength and speed agility are positively associated with executive function in overweight and obese children. Furthermore, cognitive flexibility seems to be the executive function indicator with a higher association with physical fitness, whereas planning ability and inhibition might be fitness-component specific. Public health policies should promote not only physical health, but cognitive health as well. However, exercise-based randomized controlled trials are needed to extend our results.

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Figure 1. Associations between an overall physical fitness Z-score with executive function indicators (n=100).

β values are standardized. Regression analyses were adjusted for the following covariates: sex, age, puberty stage, wave of participation, parental educational level, and intelligence quotient. The bold font is used to highlight significance level at $p<0.05$ and an asterisk (*) is used to highlight statistically significant values after an adjustment for multiple comparisons using the Benjamini and Hochberg method. The overall physical fitness Z-score was calculated as the mean of the Z-scores of each physical fitness component. The values were inverted for Trail Making Test and Stroop Test so that higher values indicate better results.