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Keywords:	Aerobic fitness, Brain function, Cognition, EEG, Executive function, Health, P3, Youth

Fitness, physical activity, working memory and neuroelectric activity in children with overweight/obesity

Fitness, physical activity and brain activity

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Abstract

The aim of the present study was to examine the associations of physical fitness, sedentary time and physical activity (PA) with working memory and neuroelectric activity in children with overweight/obesity. Seventy-nine children with overweight/obesity (10.2 ± 1.1 years old) participated in this cross-sectional study. We assessed physical fitness components (i.e., muscular strength, speed-agility and cardiorespiratory fitness) using the ALPHA battery. Sedentary time and PA were assessed by GT3X+ accelerometers (ActiGraph, Pensacola, FL, USA). Working memory was assessed using the Delayed Non-Matched-to-Sample task; mean reaction time (RT) and response accuracy were registered. Neuroelectric activity (i.e., P3 amplitude and latency) was registered using the ActiveTwo System of BioSemi electroencephalogram. Higher upper-limbs absolute strength was associated to lower response accuracy ($P=0.023$), while higher lower-limbs relative-to-weight strength was associated with larger P3 amplitude ($P<0.05$). Higher speed-agility and cardiorespiratory fitness levels were associated with shorter mean RT and larger P3 amplitude, and speed-agility was also associated with shorter P3 latency (all $P<0.05$). Vigorous PA was associated with larger P3 amplitude ($P<0.05$). No associations were found for sedentary time or the rest of PA intensities ($P\geq0.05$). In addition to cardiorespiratory fitness, muscular strength and speed agility are also associated with working memory and neuroelectric activity in children with overweight/obesity. The association between PA and working memory is intensity-dependent, as significant findings were only observed for vigorous PA. Randomized controlled trials in this population would help to better understand whether improvements in different components of fitness and PA lead to better working memory and underlying brain function.

Keywords

Aerobic fitness; Brain function; Cognition; EEG; Executive function; Health; P3; Youth

1. Introduction

Apart from the well-known benefits of physical fitness and physical activity (PA) on youth's physical health,[1,2] low levels of both fitness and PA might be further related to poorer executive function and brain health in children.[3] These detrimental associations have been also found in individuals with obesity.[4–6] In fact, childhood obesity has been negatively associated with the structure and function of several brain regions that underlie executive function,[6,7] as well as with impairments in executive function processes per se, particularly working memory.[8] These associations, together with the fact that fitness and PA may be protective factors against the development of obesity, suggest that optimal levels of physical fitness and PA might attenuate the adverse influence of obesity on executive function.

In particular, within the various executive function domains, working memory is of high importance for learning and academic performance in children.[9] There are only three studies examining the cross-sectional association between physical fitness components and working memory in children with normal weight.[10–12] While two of them focused on cardiorespiratory fitness showing that higher levels of this component were associated with better performance during a working memory task; only one examined both cardiorespiratory fitness and muscular strength and showed that only muscular strength was related to better working memory.[12] In terms of sedentary time and PA, higher amounts of self-reported sedentary time were cross-sectionally associated with lower performance during a working memory task in children,[13] whereas total daily PA and moderate-to-vigorous PA (MVPA) were not associated with working memory.[14] However, no studies included speed-agility, a key component for executive function,[4,15] in relation to working memory, neither different PA intensities (i.e., light, moderate, or vigorous) or PA estimations from different accelerometer locations (e.g., hip or wrist) and cut-points which might influence its association with the outcome.[16,17]

Event-related brain potentials (ERPs) (e.g., P3 component) during a cognitive task may afford us to a better understanding of the neural and executive function correlates of physical fitness and PA.[18] Specifically, previous studies have shown that higher-fit children, in term of cardiorespiratory fitness, have larger amplitude (i.e., increased attentional resource allocation during stimulus engagement) and shorter latency (i.e., faster processing speed) of the P3 component than their lower-fit peers while performing an attentional inhibition task.[19,20] However, no previous studies examined other physical fitness components (i.e., muscular strength or speed-agility) or sedentary time and PA in relation to the neuroelectric activity underlying working memory in children.

Importantly, all the aforementioned studies have focused on healthy children with normal weight. Based on previous research declaring the negative influence of childhood obesity on executive function,[7,8] the aim of the present study was to investigate the association of different physical fitness components (i.e., muscular strength, speed-agility, and cardiorespiratory fitness), sedentary time and PA with working memory and neuroelectric activity in a sample of children with overweight/obesity. Given previous research on the association between physical fitness, physical activity, and executive functions,[3] we hypothesized that physical fitness components and PA, but not sedentary time, would positively relate to working memory and neuroelectric activity.

2. Materials and Methods

Participants

Participants in this study were recruited from the ActiveBrains project (http://profith.ugr.es/activebrains). The complete methodology, procedures and inclusion/exclusion criteria for the project has been described elsewhere.[21] Briefly, the study was conducted in three waves of participation and, initially, a total of 110 children with overweight/obesity (i.e., defined as such according to sex-and-age specific international World Obesity Federation cut-off points) aged 8–11 years were recruited from Granada (Spain). The present study focuses only upon the baseline assessment data prior to randomization. A final sample of 79 children with overweight/obesity (10.2 ± 1.1 years old; 64.6% boys) with complete baseline data for physical fitness, sedentary time, PA, working memory (i.e., >15 trials completed per task condition), and ERPs (i.e., neuroelectric activity non-artifacted) were included in this study.

Description and characteristics of the study were given to parents or legal guardian and a written informed consent was provided by them. The ActiveBrains project was approved by the Ethics

Committee on Human Research of the University of Granada, and was registered in ClinicalTrials.gov (identifier: NCT02295072).

Physical fitness components

Components of physical fitness (i.e., muscular strength, speed-agility and cardiorespiratory fitness) were assessed using the ALPHA (Assessing Levels of Physical fitness and Health in Adolescents) health-related physical fitness test battery for children and adolescents which has been shown to be valid, reliable and feasible for the assessment of physical fitness in youth.[22]

Briefly, upper-limbs muscular strength and lower-limbs muscular strength were assessed using the maximum handgrip strength test and the standing long jump test, respectively. A digital hand dynamometer with an adjustable grip (TKK 5101 Grip D, Takei, Tokyo, Japan) was used to assess the handgrip strength. Each child performed the test twice, and the mean score of the maximum score of left and right hands was calculated as an absolute measurement of upper-limbs muscular strength (kg). The standing long jump test was performed three times and the longest jump was recorded in centimeters (cm) as a relative measurement of lower-limbs muscular strength. For exploratory analyses, we computed a relative-to-body weight measurement from upper-limbs muscular strength (kg / body weight) and an absolute measurement from lower-limbs muscular strength (cm * kg).

Speed-agility was assessed using the 4×10-meter shuttle-run test (4×10m SRT). The test was performed twice and the fastest time was recorded in seconds. Since a longer completion time indicates a lower fitness level, for analyses purposes we inverted this variable by multiplying test completion time (sec) by −1. Thus, higher scores indicated higher speed-agility levels.

Cardiorespiratory fitness was assessed through the 20-meter shuttle-run test (20m SRT).[23] This test was performed once and always at the end of the fitness battery testing session. The total number of completed laps was registered.

Sedentary time and physical activity

Sedentary time and PA were assessed by accelerometer (GT3X+, ActiGraph, Pensacola, FL, USA). Children wore simultaneously two accelerometers located on the right hip and non-dominant wrist during 7 consecutive days (24h/day), and they were instructed to remove them only for water activities (i.e., bathing or swimming). Data was presented from the hip-location and also from non-dominant wrist as supplementary. Further information about the whole data processing criteria is shown in **Supplementary material 1**. In brief, total minutes per day of sedentary time, light PA, moderate PA, vigorous PA, and MVPA were calculated using the GGIR package in R (v. 1.5-18, https://cran.r-project.org/web/packages/GGIR/)[24] and the previously published cut-points by Hildebrand et al.[25,26]

Working memory

All participants completed a modified version of the Delayed Non-Match-to-Sample (DNMS) computerized task to assess working memory.[27] All trials were presented focally on a computer screen using E-Prime software (Psychology Software Tools, Pittsburgh, PA). Each trial consisted of two phases: sample and choice. The sample phase included a memory set of four sequential stimuli. We adapted stimuli for children, and thus *Pokemon* cartoons were presented on a blue background. Participants were asked to remember 4 stimuli displayed for 500 ms with a 1000 ms inter-stimulus interval between them. After the presentation of the 4 stimuli and after a 4000 ms delay interval, a target consisting in 2 different cartoons presented together was shown during the choice phase for 1800 ms (**Figure 1**). During this phase, participants were asked to select the cartoon that was not shown on the 4 previous stimuli.

A total of 16 practice trials plus 140 experimental trials were presented. The practice phase was carried out before the presentation of experimental trials to make sure that all participants were familiarized with the cartoons and started the experimental task in equal conditions. Then, the 140 total trials were shown in 4 blocks of 35 trials each in a randomized order. For the low memory load condition (i.e., 40 trials), the 4 stimuli presented during the sample phase were repeated, whereas for the high memory load condition (i.e., 100 trials) 4 different stimuli were presented before the choice phase demanding greater working memory capacity. Duration of the task ranged from 35 to 45 min. Mean reaction time (RT) and response accuracy (%) were registered.

Neuroelectric activity

Neuroelectric activity was recorded from 64 electrode sites (Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz, Iz, Fp1/2, AF3/7/4/8, F1/3/5/7/2/4/6/8, FC1/3/5/2/4/6, FT7/8, T7/8, C1/3/5/2/4/6, TP7/8, CP1/3/5/2/4/6, P1/3/5/7/9/2/4/6/8/10, PO3/7/4/8, O1/2) arranged in an extended montage based on the International 10–10 system[28] using the ActiveTwo System of BioSemi (24-bit resolution, biopotential measurement system with Active Electrodes; Biosemi, Amsterdam, Netherlands). Prior to electroencephalography (EEG) recordings, inter-electrodes impedance was <10kΩ with CMS and DRL sites serving as online (active and passive) ground electrodes. Details of the online BioSemi reference method can be found at http://www.biosemi.com/faq/cms&drl.htm. The EEG was conducted by using a 64-channel Active Two BioSemi EEG recording system (BioSemi; Amsterdam, Holland) using a sampling rate of 1024 Hz and a 100-Hz low-pass filter.

Information about EEG data pre-processing and processing is shown in **Supplementary material 2**. Briefly, the P3 component was defined as the largest positive-going peak within a 300 to 800 ms latency window. Data were then averaged across a 9-electrode site region of interest over the parietal and occipital regions (P1/Z/2, PO3/Z/4, O1/Z/2). Amplitude was measured as the difference between the mean pre-stimulus baseline and mean peak-interval amplitude; while peak latency was defined as the time point corresponding to the maximum peak amplitude.

Potential confounders

Sex, age, peak height velocity (PHV), body mass index (BMI), wave of participation, parental educational level and intelligence quotient (IQ) were used as potential confounders in the analyses. PHV is an indicator of maturity during childhood and adolescence and we used age and anthropometric variables to calculate it following Moore's equations.[29] Wave of participation was a categorical variable according to the moment of participation (wave 1, 2, or 3) of each child in the study. Parental educational level was assessed by a self-report questionnaire filled by the parents and we combined responses of both parents as: neither of them had a university degree; one of them had a university degree; both of them had a university degree.[30] The total composite

IQ was assessed by the Spanish version of a valid and reliable tool named The Kaufman Brief Intelligence Test (K-BIT).[31]

Statistical analysis

The characteristics of the study sample are presented as means and standard deviations (SD) or percentages. Prior to all analyses, the extreme values were winsorized to limit their influence; this method allows replacing extreme high/low values for the closest (highest/lowest) valid value.[32] After checking for normal distribution, response accuracy from the low working memory load was normalized since it showed skewed distribution. Interaction analyses were performed between sex and physical fitness, sedentary time and PA on the outcomes. No significant interactions with sex were found (all $Ps \geq 0.10$) so analyses were carried out for the whole sample. Paired sample t-test was used to analyze differences in working memory (i.e., mean RT and response accuracy) and neuroelectric (i.e., P3 amplitude and latency) outcomes between low and high working memory loads. Bivariate Pearson correlations were performed to test the associations between potential confounders and working memory and neuroelectric outcomes. Statistical summary of these correlations is provided in **Table S1**.

Hierarchical linear stepwise regression analyses were performed to examine the associations of physical fitness, sedentary time and PA (i.e., data from both hip and wrist locations) with working memory and neuroelectric measurements. Stepwise method was used and all potential confounders (i.e., sex, age, PHV, BMI, wave of participation, parental educational level and IQ) were included into step 1 to test their association to the outcomes (working memory or neuroelectric activity). This step was performed to select the potential confounders that explain the higher amount of variance of their association with working memory and neuroelectric outcomes (see tables footnotes). Subsequently, hierarchical regressions were carried out entering each physical fitness, sedentary time and PA variable into step 2 in separate regression analyses after the inclusion of confounders previously found significantly associated to the outcomes in step 1.

Additionally, computation of the median for all the predictors was performed in order to visually represent the relationship of physical fitness, sedentary time and PA with P3 amplitude and latency. A significance level of $P<0.05$ was set. Additionally, multiple comparisons correction was performed by independent variables (i.e., physical fitness, and sedentary time and PA) using the Benjamini-Hochberg method.[33] All the statistical procedures were performed using the SPSS software for Mac (version 22.0, IBM Corporation).

3. Results

Working memory: Reaction time and response accuracy

Paired samples t-test showed a significant difference between low and high working memory loads with respect to response accuracy (82.99 ± 12.21% and 68.92 ± 13.47%, respectively; $P<0.001$). For mean RT, no significant difference was observed between low and high working memory loads (920.28 ± 143.25 ms and 907.80 ± 142.74 ms, respectively; $P=0.174$).

Physical fitness

The descriptive characteristics of the study sample can be found in **Table 1**. Higher upper-limbs absolute strength was associated with lower response accuracy in the high load ($\beta=-0.270$, $P=0.023$) (**Table 2**). This association remained significant after exploratory analysis with relative-to-body weight upper-limbs strength fitness ($\beta=-0.223$, $P=0.032$). Higher speed-agility was associated with shorter mean RT in both the low and high loads ($\beta=-0.231$ and $\beta=-0.251$, respectively; both $P<0.05$). Higher cardiorespiratory fitness was also associated with a shorter mean RT in the high load ($\beta=-0.243$, $P=0.031$). No significant association was observed between lower-limbs relative or absolute strength and working memory ($P\geq0.05$).

Sedentary time and physical activity

Higher vigorous PA was associated with higher response accuracy in the high load ($\beta=0.219$, $P=0.028$). However, the significance disappeared after correcting for multiple comparisons. No associations were observed for sedentary time and the rest of PA intensities ($P\geq0.05$). Furthermore, when performing sedentary time and PA analyses from the non-dominant wrist-placement, no associations were found with working memory ($P\geq0.05$) (**Table S2**).

Neuroelectric activity: P3 amplitude

Paired sample t-test did not show a significant difference between low and high working memory loads with respect to P3 amplitude (10.07 ± 4.33 µV and 10.14 ± 4.16 µV, respectively; $P=0.822$).

Physical fitness

Higher lower-limbs relative strength, speed-agility and cardiorespiratory fitness were associated with larger P3 amplitude in both low and high working memory loads with β ranging from 0.251 to 0.337 (all $P<0.05$) (**Table 3**). However, the associations found for lower-limbs relative strength disappeared when it was expressed in absolute terms ($\beta=0.102$ and $\beta=0.115$ for low and high P3 amplitude; $P>0.05$). No significant associations were found between upper-limbs absolute or relative strength and P3 amplitude ($P\geq0.05$). These relationships can be visually observed in **Figure 2**.

Sedentary time and physical activity

After correcting for multiple comparisons, only higher vigorous PA from hip was associated with larger P3 amplitude in the low working memory load ($\beta=0.390$; $P<0.001$) (**Table 3**). No associations were observed for sedentary time and the rest of PA intensities ($P\geq0.05$). These relationships can be graphically observed in **Figure 3**. Furthermore, when using data from the non-dominant wrist-placement (**Table S3**) and after correcting for multiple comparisons, only higher vigorous PA was associated with larger P3 amplitude in the low load ($\beta=0.289$, $P=0.008$).

Neuroelectric activity: P3 latency

Paired sample t-test showed a significant difference between low and high working memory loads with respect to P3 latency (469.55 ± 76.55 ms and 495.09 ± 81.48 ms, respectively; $P=0.008$).

Associations of physical fitness, sedentary time and PA with P3 latency can be observed in **Table S4**, and in **Table S5** for the PA data from non-dominant wrist.

Physical fitness

Briefly, higher speed-agility was associated with shorter P3 latency in both low and high loads ($\beta=-0.252$ and $\beta=-0.277$, respectively; both $P<0.05$), as well as cardiorespiratory fitness but only in the low load ($\beta=-0.314$, $P=0.008$).

Sedentary time and physical activity

No associations were found between sedentary time, PA, and P3 latency using either the hip or wrist data ($P \geq 0.05$).

4. Discussion

Main findings

Our findings contribute to the existent literature by suggesting that: 1) Not only cardiorespiratory fitness, as shown in previous research, but also speed-agility were consistently associated with working memory (i.e., shorter mean RT) and the P3 component (i.e., larger amplitude and shorter latency). However, inconsistent findings were observed for muscular strength, with upper-limbs absolute strength associated with lower response accuracy, and lower-limbs relative strength associated with larger P3 amplitude; 2) The relationship of PA with working memory and neuroelectric activity was intensity-dependent and seemed consistent across accelerometer locations and cut-points (i.e., hip and wrist). Thus, only vigorous PA related to a higher response accuracy and to a larger P3 amplitude regardless of the accelerometer location.

Physical fitness components and working memory

In the present study, speed-agility and cardiorespiratory fitness were associated with shorter RT observed in the high working memory load. Despite the lack of studies in children with overweight/obesity, our results regarding cardiorespiratory fitness are in line with several previous studies carried out in children with normal weight.[10,11] In these studies, higher-fit children had a higher response accuracy than their lower-fit peers during a working memory task. Similarly, in a randomized-controlled trial, increases in VO_2max resulting from a PA intervention consisting in 70 min of daily MVPA were associated with improvements in children's working memory.[34] A recent systematic review showed that complex motor skills (i.e., speed-agility) are strongly related to higher-order cognitive skills, which may include working memory.[15] Whereas our findings on fitness and working memory performance were observed for mean RT, the majority of previous research found these associations for response accuracy.[9,10] However, previous studies included a sample of children with normal weight, and since our study was carried out in children with overweight/obesity, it could be that in the present study, RT was a more sensitive index to detect fitness associations in this population. Thus, it may be that children in the present study carried out more proactive cognitive strategies (i.e., early selection, shorter RT) in order to achieve optimal completion of task goals via regulation of attentional engagement.[20] Collectively, as our results strengthen the existent evidence suggesting that different components of physical fitness may positively affects working memory,[3,34] future studies should focus on conducting intervention programs to gain causal evidence for the role of different fitness components on working memory in children with overweight/obesity.

In regards with muscular strength, we found inconsistencies in the associations between upper-limbs absolute strength and lower-limbs relative strength with respect to working memory. To our knowledge, only one study analyzed this relationship in children with normal weight, reporting contradictory findings with respect to ours with upper-limbs absolute strength in overweight/obese.[12] In that study, overall muscular strength was associated with higher response accuracy during high working memory load. Possible explanations for the discrepancies between studies include the use of different types of strength (i.e., absolute versus relative), different types of musculature involve (i.e., upper- versus lower-limbs versus overall muscular strength), or different types of working memory task (i.e., DNMS versus n-back). In particular, the reason for our negative association between upper-limbs absolute strength and response accuracy may be the overweight/obese status of our sample as it has been speculated previously,[35] as well as the higher levels of upper-limbs absolute strength of these individuals in our study (i.e., there was a significant correlation between body weight and upper-limbs absolute strength of $r=0.542$, $P<0.001$). In fact, this negative association remained significant after exploratory analysis using a relative-to-body weight measurement of upper-limbs strength. In this context, a recent systematic review reported shorter RT but more commission errors (i.e., less response accuracy) among children with higher BMI.[35] This fact may derive from a higher impulsivity of children with overweight/obesity[36] that are also the strongest ones, which may in turn explain the lower response accuracy observed in our study.

In general, the association found between cardiorespiratory fitness and mean RT was observed in the high working memory load. This indicates that higher-fit children were faster in responding and that the relationship of cardiorespiratory fitness may be selective for task loads engendering greater amounts of working memory. In fact, these findings are consistent with prior studies in children with normal weight and support the idea that cardiorespiratory fitness may be particularly beneficial for more cognitively demanding processes.[10,12] Further, when comparing RTs between high and low loads, higher RTs were observed in the high load compared with the low load, although this difference did not reach the significance. On the other hand, speed-agility was associated with shorter RT in both loads, indicating faster information processing speed regardless of the working memory demands. A recent study using the same sample as in the present research found that higher speed-agility was associated with better movement competency.[37] Proper movement competency is partly determined by a neuromuscular/motor control network,[38] which may also relate to shorter RTs. Considering that a prior study showed that children with overweight/obesity exhibited larger RT than their normal weight peers,[39] it may be that children with overweight/obesity have more room for improvement from speed-agility which may be reflected by shorter RTs. However, further studies comparing children with overweight/obesity and normal weight peers with respect to speed-agility and processing speed are needed to draw firm conclusions.

Physical fitness components and neuroelectric activity

To the best of our knowledge, this is the first study to investigate the association between multiple physical fitness components, sedentary time, PA, and ERPs (i.e., P3 amplitude and latency) during a working memory task in overweight/obese. To date, the majority of studies focused only on cardiorespiratory fitness and used an attention or inhibition task (mainly modified flanker tasks).[3] In our study, cardiorespiratory fitness was associated with higher P3 amplitude across memory loads. This concurs with previous findings showing that higher-fit children exhibited larger P3 amplitude or shorter P3 latency than their peers.[19,20] All these previous studies split the sample into two extreme fitness groups (i.e., high- and low-fit children) excluding those with middle level, what make possible that cardiorespiratory fitness group differences occurred via a physical fitness threshold.[3] However, in the present study we also obtained positive results with cardiorespiratory fitness as a continuous outcome by including the full range of this variable (i.e., as has been previously recommended).[3]

Apart from cardiorespiratory fitness, this study also provides novel data on the positive association of muscular strength and speed-agility with P3 amplitude and latency during a working memory task in children with overweight/obesity. Although direct comparisons cannot be made, our findings with lower-body muscular strength may be explained by the fact that muscular fitness is associated with a variety of health benefits in children[40] which have been associated with enhanced working memory.[41,42] However, this must be interpreted with caution since the associations for lower-limbs relative strength disappeared when it was expressed in absolute terms. Across all fitness components, speed-agility and cardiorespiratory fitness had the highest number of significant associations with working memory performance and P3 amplitude and latency, which may be explained by previous findings in the same sample showing that these two fitness components were also the main ones associated to brain volumes.[4] Specifically, these components were related to increased volume of cortical and subcortical brain structures[4] that have been shown to directly influence memory in children (e.g., hippocampus, premotor cortex, etc.).[43] These key neural structures subserving working memory processes are still developing throughout childhood,[44] suggesting that some brain structures might be highly susceptible to environmental factors such as engagement in aerobic exercise and motor tasks during development.[45] However, further randomized-controlled trials should confirm these findings.

The positive associations found for each fitness component with P3 amplitude were observed regardless of working memory load. This is supported by a prior study using an inhibitory control task, which showed that higher-fit children exhibited larger P3 amplitude than their lower-fit peers across task's conditions.[19] However, the majority of literature has declared that the association between physical fitness and P3 amplitude appears when task demands increase.[3,20] Despite this, the associations found across conditions in the present study may be due to different arguments. For instance, the characteristics and design of the DNMS task may be a limitation itself to detect selective associations of fitness with attentional resources allocation during high working memory processes.

Sedentary time, physical activity, working memory and neuroelectric activity

In regards to the relationship between sedentary time, PA, and working memory performance, we found that vigorous PA (from hip data) was associated with higher response accuracy in the high memory load. However, this finding should be interpreted with caution since the significant association disappeared after controlling for multiple comparisons. Two previous cross-sectional studies investigated this relationship in children with normal weight.[13,14] They showed non-significant associations of objectively-measured sedentary time, total PA, MVPA, with the Visual Memory Span task,[14] and the Spatial Span task.[13] None of these studies assessed other PA intensities (i.e., light, moderate or vigorous PA). Vigorous PA was also related to a larger P3 amplitude and it was consistent across accelerometer locations (i.e., hip or non-dominant wrist). Despite no previous study has analyzed the relation between PA and neuroelectric activity during working memory task, our association between vigorous PA and P3 amplitude may be due to an intensity-dependent relation of PA with working memory. This is supported by an intervention study where two different types of PA intensity-based physical education classes were delivered to an intervention and a control group.[46] In this study, a significant PA intensity effect was found since the children from the intervention group (i.e., higher PA intensity classes) had better performance after the program on a working memory test battery in comparison with their peers in the control group (i.e., regular physical education lessons). Another important finding from our study was the consistency between accelerometer's locations (i.e., hip and wrist) with respect to the relation of sedentary time and PA with working memory and neuroelectric activity. However, the lack of evidence in this respect indicate that these findings are preliminary and call for more studies investigating the association of different PA intensities and accelerometer-locations with the neuroelectric system in children.

Limitations and strengths

Several limitations of the present study must be highlighted. First, the cross-sectional design does not allow us to draw causal interpretations. Second, PA such as bicycling and swimming cannot be captured by the accelerometers, and our identification of sedentary time was not sensitive to postures, so we cannot differ between different sedentary behaviors and, therefore, some standing activity could be classified as sedentary time. On the other hand, the main strength of this study was that, to the best of our knowledge, this was the first study to investigate the relationship between different physical fitness components, not only cardiorespiratory fitness, and objectively sedentary time and PA with working memory and the neuroelectric activity underlying it in a sample of children with overweight/obesity. Other strengths were the objective and standardized assessment of physical fitness, PA and the cognitive variables; the analysis of different intensities of PA; the use of all predictors as continuous variables; and the availability of sedentary time and PA data from two different accelerometer locations (i.e., hip and non-dominant wrist).

5. Perspective

Our results add to the literature on physical fitness and cognition by providing support not only for cardiorespiratory fitness relation, but also muscular strength and speed agility relation to working memory and the neuroelectric activity (i.e., P3 component) in children with overweight/obesity. Speed-agility and cardiorespiratory fitness were the fitness components more consistently related to both working memory performance and neuroelectric activity. The association of PA with working memory and neuroelectric activity was intensity-dependent, since only vigorous PA demonstrated a consistent (i.e., for both hip and wrist's locations) relationship. From a public health perspective, promoting physical activity that enhances speed-agility and cardiorespiratory fitness, and also reaches high intensity PA levels, may be important not only for the physical health, but also for working memory and underlying neuroelectric activity in children with overweight/obesity. However, our observational findings need to be supported with exercise-based randomized controlled trials inducing improvements in different fitness and PA components to test whether such improvements lead to better working memory in overweight/obese youth.

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Table 1. Descriptive characteristics of the study sample.

	All (n=79)	Boys (n=51)	Girls (n=28)
Sociodemographic characteristics			
Age (years)	10.2 ± 1.1	10.3 ± 1.1	10.0 ± 1.1
Peak height velocity offset (years)	–2.2 ± 1.0	–2.6 ± 0.8	–1.5 ± 1.0
Weight (kg)	57.4 ± 10.1	57.4 ± 10.0	57.5 ± 10.4
Height (cm)	145.3 ± 7.6	145.5 ± 7.5	144.9 ± 7.9
Body mass index (kg/m^2)	27.1 ± 3.5	27.0 ± 3.6	27.2 ± 3.2
Intelligence quotient (typical punctuation)	99.5 ± 12.0	97.9 ± 12.1	102.0 ± 11.6
Wave of participation, (%)			
First	14	8	25
Second	42	47	32
Third	44	45	43
Parental university level, (%)			
None of them	63	68	54
One of them	20	16	28
Both of them	17	16	18
Physical fitness			
Upper-limbs absolute strength (kg)	17.2 ± 4.2	17.7 ± 4.4	16.5 ± 3.7
Lower-limbs relative strength (cm)	106.1 ± 18.6	107.4 ± 16.8	103.7 ± 21.6
Speed-agility (sec)*	14.9 ± 1.6	14.7 ± 1.5	15.2 ± 1.6
Cardiorespiratory fitness (laps)	16.7 ± 8.1	17.7 ± 8.2	14.9 ± 7.8
Sedentary time and PA (min/day)†			

Sedentary time	827.2 ± 44.5	821.4 ± 45.9	837.7 ± 40.3
Light PA	65.8 ± 15.6	67.3 ± 15.7	63.2 ± 15.3
Moderate PA	34.3 ± 14.8	38.5 ± 15.8	26.8 ± 9.2
Vigorous PA	3.3 ± 2.8	4.0 ± 3.1	2.1 ± 1.5
MVPA	37.6 ± 16.8	42.5 ± 17.9	28.9 ± 10.1
Working memory task			
Low working memory load			
Mean reaction time (ms)*	920.3 ± 143.3	934.4 ± 156.9	894.6 ± 112.4
Response accuracy (%)	83.0 ± 12.2	81.6 ± 13.5	85.6 ± 9.0
High working memory load			
Mean reaction time (ms)*	907.8 ± 142.8	912.0 ± 153.7	900.2 ± 122.6
Response accuracy (%)	68.9 ±13.5	69.6 ± 15.1	67.7 ± 10.0
Neuroelectric measurements			
Low working memory load			
P3 amplitude (µV)	10.1 ± 4.3	10.1 ± 4.6	10.0 ± 3.9
P3 latency (ms)*	469.6 ± 76.7	417.6 ± 80.8	465.8 ± 69.4
High working memory load			
P3 amplitude (µV)	10.1 ± 4.2	10.0 ± 4.3	10.5 ± 4.0
P3 latency (ms)*	495.1 ± 81.5	503.5 ± 84.6	479.9 ± 74.5

Values are expressed as means ± standard deviations, unless otherwise indicated. PA=Physical activity; MVPA=Moderate-to-Vigorous Physical Activity. *Lower values indicate better performance. †Sedentary time and PA variables were obtained from the hip. Upper-limbs absolute strength was measured by the handgrip strength test. Lower-limbs relative strength was measured by the standing long jump test. Speed-agility was measured by the 4×10-meter shuttle run test. Cardiorespiratory fitness was measured by the 20-meter shuttle run test (20m SRT).

Table 2. Hierarchical stepwise regressions for the association of physical fitness, sedentary time and physical activity (hip) with working memory task (n=79).

	Low working memory load								High working memory load							
	Mean reaction time (ms)				Response accuracy (%)‡				Mean reaction time (ms)				Response accuracy (%)			
	R^2	R^2 change	β	P	R^2	R^2 change	β	P	R^2	R^2 change	β	P	R^2	R^2 change	β	P
Physical fitness																
Upper-limbs absolute strength (kg)	0.064	0.009	0.095	0.398	–0.103	–0.010	–0.101	0.356	0.006	0.006	0.079	0.488	0.327	0.049	–0.270	**0.023***
Lower-limbs relative strength (cm)	0.090	0.035	–0.189	0.089	0.093	0.000	–0.016	0.886	0.026	0.026	–0.162	0.155	0.299	0.021	–0.162	0.141
Speed-agility (sec)†	0.107	0.053	–0.231	**0.037***	0.105	0.011	0.107	0.327	0.063	0.063	–0.251	**0.026***	0.278	0.000	–0.001	0.995

Cardiorespiratory fitness (laps)	0.066	0.012	–0.110	0.332	0.115	0.022	0.150	0.177	0.059	0.059	–0.243	**0.031***	0.281	0.003	0.061	0.586
Sedentary time and PA (min/day)																
Sedentary time	0.059	0.005	–0.068	0.541	0.095	0.001	0.039	0.724	0.017	0.017	–0.131	0.249	0.294	0.016	0.127	0.200
Light PA	0.057	0.002	–0.046	0.679	0.093	0.000	–0.015	0.888	0.000	0.000	0.007	0.953	0.284	0.006	–0.081	0.420
Moderate PA	0.055	0.000	0.021	0.854	0.095	0.002	–0.041	0.708	0.000	0.000	0.022	0.845	0.280	0.002	0.050	0.620
Vigorous PA	0.057	0.002	–0.043	0.698	0.110	0.017	0.131	0.231	0.010	0.010	–0.098	0.389	0.323	0.046	0.219	**0.028**
MVPA	0.055	0.000	0.011	0.922	0.093	0.000	–0.015	0.893	0.000	0.000	0.004	0.975	0.284	0.006	0.080	0.429

ENMO=Euclidian norm minus one; PA=Physical activity; MVPA=Moderate-to-vigorous physical activity. The bold font is used to highlight significance level at $p<0.05$. *Statistically significant values after adjustment for multiple comparisons by independent variables using the Benjamini and Hochberg method (1995). Upper-limbs absolute strength was measured by the handgrip strength test. Lower-limbs relative strength was measured by the standing long jump test. Speed-agility was measured by the 4×10-meter shuttle run test. Cardiorespiratory fitness was measured by the 20-meter shuttle run test (20m SRT).

Potential confounders (i.e., sex, age, peak height velocity, body mass index, wave of participation, parental educational level and IQ) were included into step 1 of the hierarchical stepwise regression to test their association to the outcomes. Hierarchical stepwise regression models for low working memory load: for mean reaction time and the response accuracy, the parental educational level was included as confounder β=–0.234 and β=0.305, respectively; both $P<0.05$). Hierarchical stepwise regression models for high working memory load: for mean reaction time, no confounder was included; for response accuracy, wave of participation, age, and intelligence quotient were included as confounders (β_{wave}=–0.354, β_{age}=0.254, and β_{IQ}=0.319; all $P<0.05$). β values are standardized. †This variable was inverted so that higher values indicate better performance. ‡Normalized values were used in the analysis.

Table 3. Hierarchical stepwise regressions for the association of physical fitness, sedentary time and physical activity (hip) with P3 amplitude in the parieto-occipital region low and high working memory loads (n=79).

	Low working memory load				High working memory load			
	R^2	R^2 change	β	P	R^2	R^2 change	β	P
Physical fitness								
Upper-limbs absolute strength (kg)	0.058	0.006	–0.076	0.495	0.000	0.000	–0.021	0.851
Lower-limbs relative strength (cm)	0.103	0.051	0.227	**0.040***	0.070	0.070	0.264	**0.019***
Speed-agility (sec)*	0.157	0.105	0.325	**0.003***	0.128	0.128	0.358	**0.001***
Cardiorespiratory fitness (shuttles)	0.165	0.113	0.337	**0.002***	0.063	0.063	0.251	**0.025***
Sedentary time and PA (min/day)								
Sedentary time	0.067	0.042	–0.122	0.279	0.003	0.003	–0.055	0.630

Light PA	0.088	0.036	0.189	0.089	0.019	0.019	0.140	0.220
Moderate PA	0.088	0.036	0.191	0.085	0.020	0.020	0.141	0.214
Vigorous PA	0.204	0.152	0.390	**<0.001***	0.075	0.075	0.274	**0.015**
MVPA	0.106	0.054	0.233	**0.035**	0.029	0.029	0.169	0.135

ENMO=Euclidian norm minus one; PA=Physical activity; MVPA=Moderate-to-vigorous physical activity. The bold font is used to highlight significance level at $p<0.05$. *Statistically significant values after adjustment for multiple comparisons by independent variables using the Benjamini and Hochberg method (1995). Upper-limbs absolute strength was measured by the handgrip strength test. Lower-limbs relative strength was measured by the standing long jump test. Speed-agility was measured by the 4×10-meter shuttle run test. Cardiorespiratory fitness was measured by the 20-meter shuttle run test (20m SRT).

Potential confounders (i.e., sex, age, peak height velocity, body mass index, wave of participation, parental educational level and IQ) were included into step 1 of the hierarchical stepwise regression to test their association to the outcomes. Hierarchical stepwise regression models for the P3 amplitude from the low working memory load was adjusted by wave of participation (β=0.228, P=0.043). Hierarchical stepwise regression models for the P3 amplitude from the high working memory load was not adjusted by any confounder. β values are standardized. *This variable was inverted so that higher values indicate better performance.

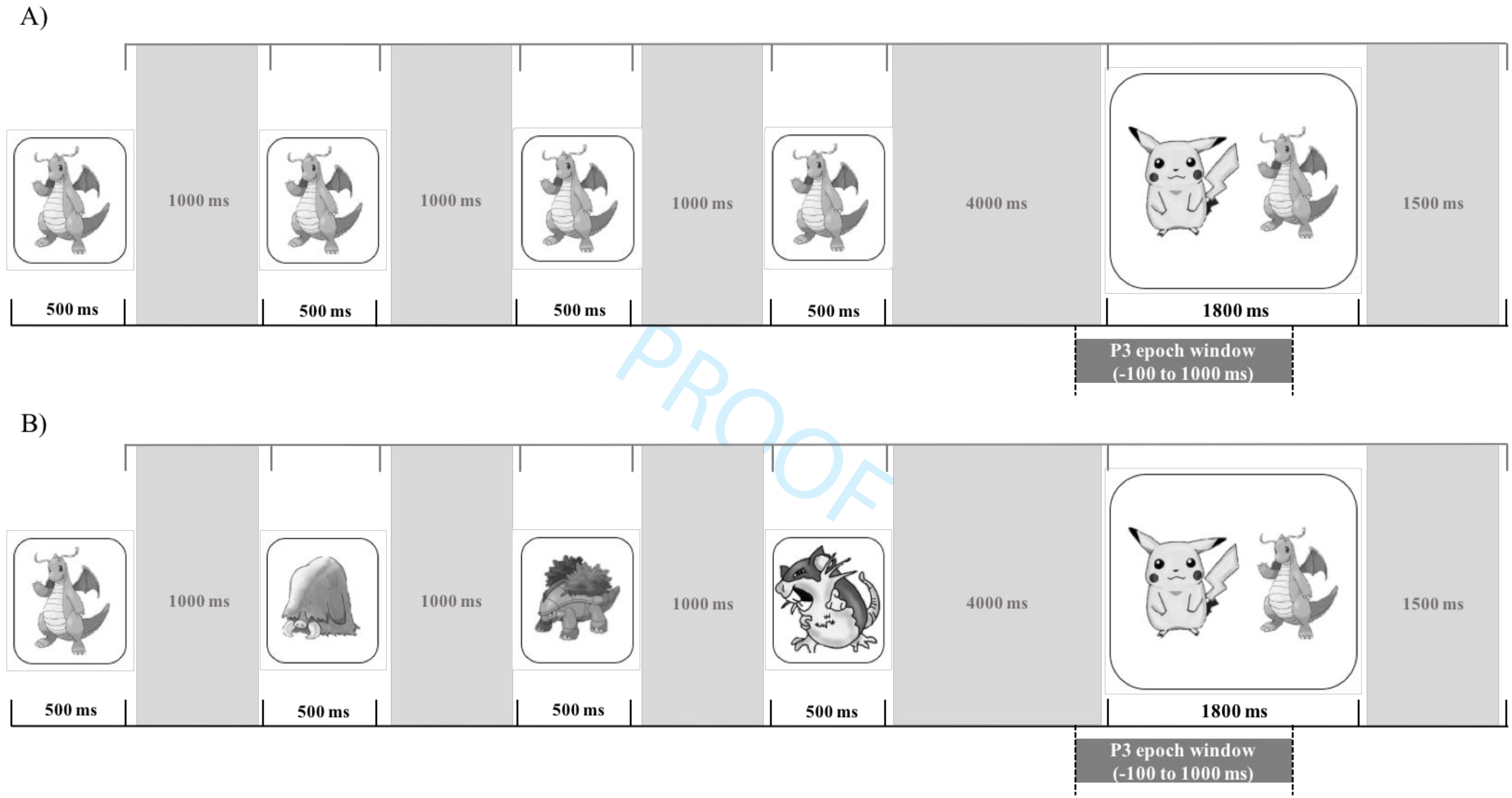

Figure 1. Low load (A) and high load (B) delayed-non-match to sample working memory task, and epoch window for the extraction of P3 amplitude and latency.

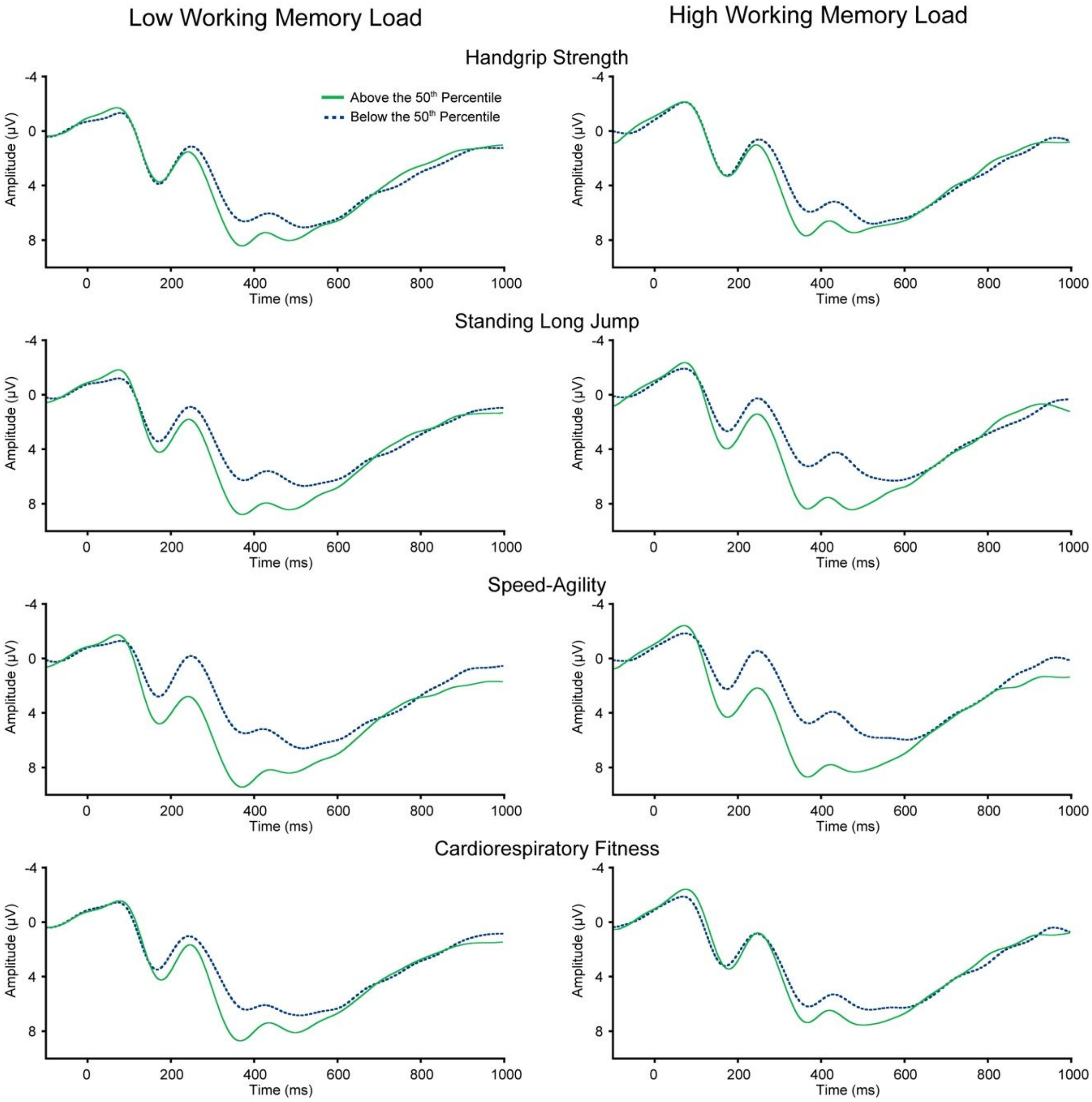

Figure 2. Median split waveforms time-locked to the onset of the choice stimulus for each domain of physical fitness.

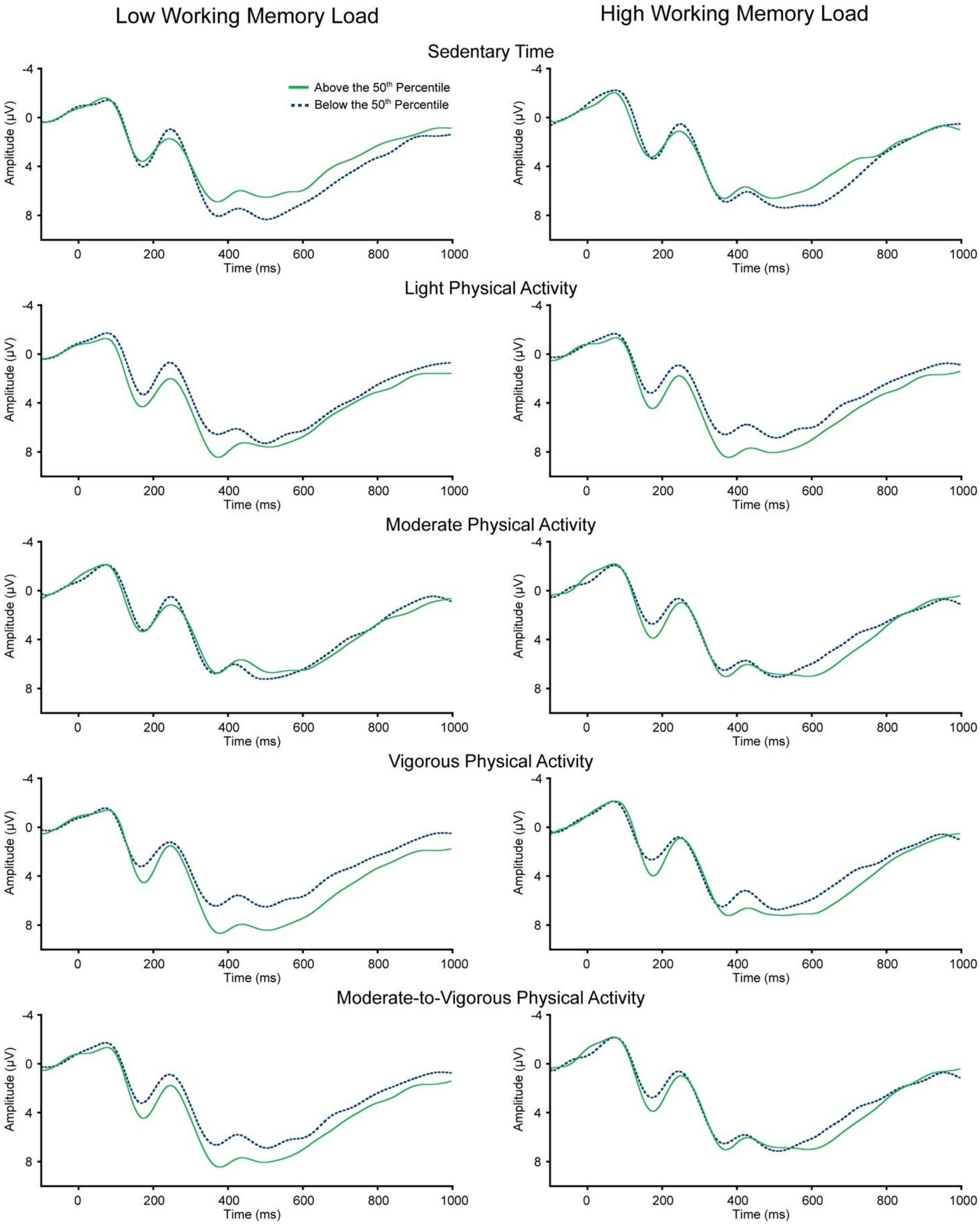

Figure 3. Median split waveforms time-locked to the onset of the choice stimulus for the relation of sedentary time and physical activity.