This work is a preprint, not peer reviewed.

Title: The relationship of physical fitness and motor competence with behavioral and neuroelectric indices of attention in preschool children

Running Head: Preschool fitness, motor competence, and ERP/EEG

Shih-Chun Kao¹, Yu-Jung Tsai², Shu-Shih Hsieh³, Sara Schmitt⁴, & Tsung-Min Hung²

¹Department of Health and Kinesiology, Purdue University

²Department of Physical Education, National Taiwan Normal University

³Department of Psychology, Northeastern University

⁴Department of Human Development and Family Studies, Purdue University

Please cite as: Kao, S. C., Tsai, Y. J., Hsieh, S. S., Schmitt, S., & Hung, T. M. (2021).

The relationship of physical fitness and motor competence with behavioral and neuroelectric indices of attention in preschool children. SportRxiv.

<https://doi.org/10.31236/osf.io/wckqp>

All authors have read and approved this version of the manuscript. This article was last modified on June 4th, 2021

Correspondence

Tsung-Min Hung

Address: 162, sec.1, He-Ping East Rd., Taipei, Taiwan

Email: ernesthungkimo@yahoo.com.tw

Abstract

The present study examined the associations of physical fitness and motor competence with P3 and alpha desynchronization (ERD), two neuroelectric indices of brain development underlying controlled attention, in 4-6 year-old preschool children. All participants completed physical fitness and motor competence test batteries and an auditory oddball task while electroencephalogram (EEG) was recorded. Results revealed that increased muscular power, muscular endurance, physical fitness, and motor competence were associated better attentional task performance. Analysis on neuroelectric indices showed that muscular endurance was related to increased P3 amplitude, while the increases in physical fitness and motor competence were associated with greater upper alpha (10-12 Hz) ERD following the stimulus evaluation and response selection. Further, the negative associations of physical fitness and motor competence with task response time were mediated by the upper alpha ERD. These findings highlight the importance of early childhood motor competence and physical fitness, especially muscular endurance, to neurocognitive function.

Key words: physical performance, auditory oddball, EEG, P3, Alpha ERD

Early childhood is a time of rapid postnatal brain maturation concurrent with acquisition of cognitive abilities relying on the orienting and executive attention networks (Garon, Bryson, & Smith, 2008). Orienting refers to the ability to prioritize sensory input by focusing on a modality or location while the executive attention system elaborates processing by inhibiting and facilitating the orienting system (Petersen & Posner, 2012). During the preschool years, these two attention systems are vital for development and achievement because they support self-regulatory processes of cognitive and emotional reactivity to the environment (Rothbart, Sheese, Rueda, & Posner, 2011). The development of these attention networks has been characterized by the progression from global to focalized brain activation patterns during controlled attentional processes, suggesting a fine-tuned brain mechanism of neural efficiency as fewer neurons are recruited to carry out task-related computational processing (Durstun et al., 2006; Rothbart et al., 2011). Such a developmental increase in neural efficiency can be manifested by neuroelectric mechanisms of neural inhibition to task-irrelevant processing through the P3 component of event-related brain potentials (ERP) (Polich, 2007; Riggins & Scott, 2020)

P3 (also known as P300 or P3b) is a neuroelectric marker that reflects childhood neurocognitive development (Riggins & Scott, 2020). P3 is a positive ongoing deflection of brain potential during the stimulus evaluation and indicates the updating of mental representation as a result of top-down controlled attention reacting to a bottom-up stimulus (Polich, 2007). P3 has widespread and synchronous neural generators centered at the cingulate cortex linking frontal-mediated attention and updating to memory storage operated in the temporal/parietal brain areas (Kim, 2014; Polich, 2003;

Soltani & Knight, 2000). The neural substrates of P3 correspond with the orienting and executive networks (Petersen & Posner, 2012; Posner, Rothbart, Sheese, & Voelker, 2012), which coordinate bottom-up vigilance and top-down control over monitoring for, resolution of, and responding to conflicts (Rothbart et al., 2011). P3 can be elicited during tasks requiring attentional and executive control processes, with increasing amplitude reflecting greater neural inhibition to irrelevant processing while allocating attentional resources to the task at hand and decreasing latency reflecting a faster speed of stimulus categorization (Polich, 2007). From early childhood to adolescence, P3 amplitude increases and P3 latency decreases (Riggins & Scott, 2020; van Dinteren, Arns, Jongsma, & Kessels, 2014), reflecting the maturing functional brain mechanism in response to environmental stimuli through more effective neuroinhibition (Polich, 2007).

The developmental trajectory of P3 can be facilitated through increased childhood physical fitness. Research has demonstrated that greater aerobic fitness in school-aged children is associated with increased P3 amplitude and/or decreased P3 latency (Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Hillman, Castelli, & Buck, 2005; Pontifex et al., 2011; Raine et al., 2018) along with superior academic achievement and cognitive performance during tasks requiring attention and executive control (Donnelly et al., 2016; Hillman et al., 2009; Hsieh et al., 2020; Kao et al., 2017; S. C. Kao, Westfall, Parks, Pontifex, & Hillman, 2017; Raine et al., 2018). These fitness-related beneficial effects on P3 are thought to manifest in enhanced functional integrity of temporal and parietal lobes (Shih Chun. Kao et al., 2020), given that the functional connectivity related to these brain regions underlie the associations of dorsal/ventral attention and the frontoparietal executive control networks with aerobic fitness (Talukdar

et al., 2018). Recent research has extended this association to preschool children, with preliminary evidence showing a positive correlation between distance walked in a 6-min walking test, as an estimate of aerobic fitness, with P3 amplitude during an auditory stimulus discrimination task (Keye et al., 2021), suggesting the potential importance of aerobic fitness to neuroelectric function during early childhood. However, the existing literature lacks an understanding of P3 in relation to other fitness domains and motor skills, which are closely related to physical health outcomes (Robinson et al., 2015; Smith et al., 2014) and neurocognitive development (Diamond, 2000).

Of the various fitness domains, muscular fitness has been identified as an important developmental factor that is related to increased childhood cognitive function (Haapala et al., 2015; Kao et al., 2017). Such beneficial associations are beyond the behavioral levels, as research has shown a positive relation between muscular fitness and P3 amplitude in preadolescent children (Mora-Gonzalez et al., 2019; Tsai et al., 2017). During the preschool years, superior attention has been correlated with increased muscular fitness (Tsai et al., 2020) and a 10-week exercise program designed to promote muscle strength was found to result in a marginal improvement in attention (Wick, Kriemler, & Granacher, 2021). Further, using a pre-experimental design (e.g., no control group), an intervention study that included an 8-week soccer program showed that kindergarten children improved muscular endurance and flexibility, as measured by the 60s sit-up and sit-and-reach tests, along with enhanced cognitive performance, larger P3 amplitude, and shorter P3 latency following the intervention (Chang, Tsai, Chen, & Hung, 2013). These findings suggest that muscular and other health-related fitness may play roles in the developmental changes in P3. However, it remains unclear

whether individual differences in these non-aerobic fitness domains are related to P3, a neuroelectric marker of attentional processes as well as brain development during early childhood.

As a potential correlate of physical fitness (Utesch, Bardid, Büsch, & Strauss, 2019), motor competence refers to the mastery of movement skills that enable engagement in physical activities and positively relate to not only physical but also cognitive health and development (Diamond, 2000; Haapala et al., 2019; Robinson et al., 2015). Studies in school-aged children have demonstrated positive associations of motor competence with cognitive performance and P3 amplitude (Hsieh, Lin, Chang, Huang, & Hung, 2017; Hung et al., 2013). Similar beneficial associations of motor competence with behavioral outcomes of attention and executive function were observed in preschool children (Davis, Pitchford, & Limback, 2011; Tsai et al., 2020). Further, a systematic review indicated relations between motor and cognitive skills, suggesting the feasibility of complex motor intervention programs to stimulate both motor and higher order cognitive skills during early childhood (van der Fels et al., 2015). Indeed, recent intervention programs that targeted motor competence showed improvements in executive function and numeracy skills in 3-6-year-old children (Hudson, Ballou, & Willoughby, 2020; Mulvey, Taunton, Pennell, & Brian, 2018). However, none of these studies examined neural correlates of the enhanced cognitive performance in relation to motor competence, despite the sensitivity of P3 to the information processing underlying attention and executive function as well as the functional brain development during early maturation.

Event-related de/synchronization (ERS/ERD) of brain oscillations provide a complementary measure to evaluate the induced cortical oscillations of different frequency domains underlying ERP components summed over a range of oscillatory frequencies (Klimesch, Doppelmayr, Röhme, Pöhlhuber, & Stadler, 2000). Alpha oscillation (8–12 Hz) is proposed as an EEG signature indexing functional inhibition of task-irrelevant activation (Jensen & Mazaheri, 2010) and can be separated into lower alpha (8-10 Hz) and upper alpha (10-12 Hz) to respectively reflect general and specific attentional processes related to cognitive performance (Klimesch, 1999). Research has demonstrated a temporal relation between P3 and alpha ERD during an auditory oddball task, with target-elicited P3 amplitude followed by a strong parietal lower and upper alpha ERD (Yordanova, Kolev, & Polich, 2001). Given that increased alpha ERD has been associated with superior cognitive performance (Klimesch, 1999), these findings were interpreted to suggest that the extent of available attentional resources for the discrimination process as a result of inhibiting task-irrelevant processing may be related to the following reset of alpha oscillation, which indicates the release from inhibition in preparation for subsequent task performance (Klimesch, 2012; Klimesch et al., 2000; Yordanova et al., 2001). Further, parietal alpha ERD was found to be a neuroelectric representation of brain activation involving the fronto-parieto-occipital attention network (Capotosto, Babiloni, Romani, & Corbetta, 2009; Capotosto et al., 2017; Lenartowicz et al., 2016), which is central to the development of the attention network during preschool (Petersen & Posner, 2012). Despite the potential role of alpha ERD to the attentional processes underlying superior cognitive performance and the

functional manifestation of the attention network, its association with physical fitness and motor competence during early childhood remains unknown.

The purpose of this study was to investigate the role of early childhood physical fitness and motor competence with cognitive and brain function using P3-ERP and alpha ERD. These neuroelectric indices were chosen because of their functional significance to task-related attentional processes as well as brain development during early childhood. Based on the established relation of physical fitness and motor competence with P3 in preadolescent children (Hsieh et al., 2017; Hung et al., 2013; Mora-Gonzalez et al., 2019; Tsai et al., 2017), it was hypothesized that increased physical fitness and motor competence would be associated with increased P3 amplitude and decreased P3 latency. Additionally, given the well-established association of alpha ERD with enhanced cognitive performance (Klimesch, 1999), it was hypothesized that physical fitness and motor competence would be associated with greater alpha ERD. Lastly, previous research has shown the potential mediating effect of neuroelectric correlates of attention on the associations of fitness and cognitive performance in young adults (Wang, Shih, & Tsai, 2016). Thus, an exploratory mediation analysis was conducted to test the hypothesis that P3 and alpha ERD measures would mediate the associations of physical fitness and motor competence with behavioral task performance.

Methods

Participants

Ninety-two typically developing preschool children from two preschools located in Greater Taipei Area, Taiwan, were recruited to participate in this study. Participants' legal guardians completed a screening questionnaire to indicate that their child had normal, or corrected-to-normal, vision and hearing, and was right-handed, free of cardiovascular diseases, neurological diseases, and head injuries. Eligible participants and their legal guardians provided written informed assent/consent approved by the Institutional Review Board at Taipei Physical Education College and were invited to participate in two testing sessions.

Procedure

Child participants were instructed to refrain from stimulating activities (i.e., vigorous physical activity) and drinks/foods (i.e., caffeinated snacks) on the day prior to testing on two separate weekdays at their schools. Day 1. Participants and their legal guardians were escorted to a quiet, sound attenuated classroom, followed by detailed explanation of the purpose of this study. Participants who were eligible for participating in this study were then fitted with an EEG cap (~15 min). Task-related EEG was then recorded while participants performed an auditory oddball task. Day 2. Participants completed the Torrance's Thinking Creatively in Action and Movement (TCAM) test to evaluate creative thinking (Torrance, 1981) as a proxy for estimating intelligence quotient (IQ) in preschool children (Fuchs-Beauchamp, Karnes, & Johnson, 1993). Next, participants completed two test batteries to measure motor competence and physical fitness.

Motor competence test

Motor competence was assessed using nine subsets scales from the Basic Motor Ability Test-Revised (Arnheim, Sinclair, & Sinclair, 1979), including bead stringing (to test bilateral eye–hand coordination and dexterity), target throwing (to test eye–hand coordination), marble transfer (to test finger dexterity), basketball throw (to test arm and shoulder girdle explosive strength), ball kicking (to test eye-foot coordination), static balance (to test balance), prone-stand-turn position (to test speed and agility), ball striking (to test eye-hand coordination associated with striking) and agility (to test the ability to change body direction). Each of the nine subset measures were converted into standardized z-scores (speed-related measures were multiplied by -1) and then summed together to make a composite score of motor competence. This composite score has been demonstrated to afford the examination on the development of motor competence in response to intervention aimed to promote motor skills (Chang et al., 2013) and the association of motor competence with childhood cognition and its underlying neuroelectric function (Hung et al., 2013).

Physical fitness test

A battery of fitness testing consisting of crunch curl-ups (maximum repetition within 60 seconds), standing long jump (maximum distance in centimeters selected from 3 attempts), standing on one leg with eyes closed (one attempt for each leg), and sit-and-reach (maximum distance selected from 3 attempts) were used to evaluate muscle endurance, muscle power, balance, and flexibility, respectively. These tests were administered according to the guidelines of the Preschool Children Fitness Program (PCFP), which was developed by the the Department of Education of the Taipei City Government Government to evaluate the developmental trajectories of different fitness

domains as well as overall physical fitness. The overall fitness score was calculated by summing the standardized scores from the four fitness tests (Chang et al., 2013; Tsai et al., 2020).

Cognitive task

The present study employed an auditory oddball task that has been widely used to elicit P3 in young children (Riggins & Scott, 2020). The auditory modality of stimulus presentation was chosen because of its greater sensitivity to early childhood brain development (Riggins & Scott, 2020). The task was administered using Neuroscan Stim software 2.0 (NeuroScan; Charlotte, NC, USA) installed on a laptop with a binaural speaker. The task consisted of 190 standard stimuli (1000 Hz tone) and 60 target stimuli (2000 Hz tone), with each stimulus presenting for 60 ms at 70 dB. The task was divided into 5 blocks of 50 trials (38 standard and 12 target). Within each task block, the two stimulus types were presented in random order using an inter-stimulus interval randomized between 1600-1800ms. A short break (~30s) was provided between blocks and the entire task lasted about 10 minutes. Participants were asked to respond to the target stimuli by pressing a button as quickly as possible while not responding to the standard stimuli. Despite the emphasis on the simple discriminating processes between target and standard stimuli, omitting the standard stimuli while quickly responding to target stimuli required controlled attention (i.e., inhibit response to standard stimuli, inhibit the biased response selection). Thus, the associations of motor competence and physical fitness with behavioral outcomes such as hit rate, false alarm rate (FA), d' -prime (d'), and median response time (RT) to target stimuli during the task were analyzed.

Neuroelectric Assessment

EEG was measured from a 30-electrode Neuroscan Quik-Cap arranged using the International 10-20 standard (Compumedics, Charlotte, NC). Recordings were referenced to averaged mastoids, with the mid-frontal site (FPz) serving as the ground electrode, and impedance $< 10 \text{ k}\Omega$. Additional electrodes were placed above and below the left orbit and on the outer canthus of each eye to monitor electro-oculographic (EOG) activity with a bipolar recording. Continuous data were digitized at a sampling rate of 500 Hz, with a DC to 70 Hz filter, and a 60 Hz notch filter using a Neuroscan amplifier (Compumedics, Charlotte, NC). Raw EEG data collected during the cognitive task were preprocessed by offline correction for EOG artifacts using independent component analysis (Drollette et al., 2018). EOG-corrected data underwent two different processing pipelines to evaluate task-related P3-ERP and event-related de/synchronization (ERS/ERD) in frequency bands.

ERP: Epochs were created from -100 to 1000 ms around the stimulus, baseline-corrected using the -100 to 0 ms pre-stimulus period, and filtered using a zero phase-shift low-pass filter (IIR Butterworth filter) at 30 Hz (24 dB/oct). Following rejection of epochs corresponding with response errors or identified artifacts exceeded $\pm 100 \text{ }\mu\text{V}$, remaining epochs were averaged to construct ERPs. The P3 component during the target trials was quantified by the peak latency and mean amplitude within 50 ms of the largest positive peak within a 300-800 ms post-stimulus window. Given the parietally centered scalp distribution of P3 according to previous studies (Riggins & Scott, 2020), Pz was used to quantify P3 amplitude and latency (Yordanova et al., 2001).

ERS/ERD: Epochs were created from -2000 to 2000 ms time-locked to stimulus onset. Trials corresponding to a response error and containing artifacts with amplitudes exceeding $\pm 150 \mu\text{V}$ were discarded. Oscillatory EEG power was computed by a continuous Morlet wavelet transform (wavelet factor = 6) of single-trial data for the frequency band ranging from 1 to 15 Hz. Oscillatory power, defined as the square of the modulus of the resulting complex number, was averaged across trials, rescaled by the baseline values from -300 to -100 ms relative to stimulus onset, and a log10 transform of this quotient was applied ($\text{dB power} = 10 \times 10 [\text{power/baseline}]$), which allowed direct comparison of results across frequencies. The study focused on lower alpha (8-10 Hz) and upper alpha (10-12 Hz) at Pz as these frequency bands at the parietal region are correlated with P3 and cognitive performance (Klimesch, 1999; Yordanova et al., 2001).

Statistical Analysis

Data were analyzed using SPSS (SPSS v. 22, Chicago, IL) with the family-wise alpha threshold for all tests set at $p = .05$. A two-way 2 (Stimulus: Target, Standard) x 3 (Electrode: Fz, Cz, Pz) ANOVA was conducted to verify the target-specific and parietal-centered P3 and alpha ERD. A bivariate correlation was performed to identify the associations between demographic factors, fitness, motor competence, and cognitive outcomes. Hierarchical regression analysis was performed to determine the unique contribution of motor competence and fitness to cognitive outcomes by entering identified confounding variables (e.g., age) into the first step and entering the motor competence and fitness outcomes as predicting variables into the second step. Based on correlations between variables, a regression-based mediation analysis was performed using the SPSS PROCESS macro (Hayes, 2017) to examine the extent to

which the neuroelectric indices mediated the associations of physical fitness and motor competence with task performance. A bootstrapping method was employed with age being entered as a covariate in the mediation analysis.

Results

Participants' demographic and fitness variables as well as the behavioral and neuroelectric outcomes are shown in the Table 1. Seventy-six participants who completed all testing and had a minimum of 15 accepted artifact-free EEG epochs for ERP/EEG analysis (target: 34 ± 10 ; standard: 135 ± 38). Sixteen participants were excluded due to missing demographic data ($N = 2$) and contaminated EEG data (excessive movement artifacts [$N = 6$], insufficient artifact-free EEG epochs [$N = 8$]).

Based on our visual inspection, a clear target P3 was observed at Pz (Figure 1.A). This observation was confirmed by an Electrode main effect on amplitude, $F = 137$, $p < .001$, $\eta_p^2 = .647$, with Pz (15.6 ± 1.0 uv) showing significantly larger amplitude compared with Cz (12.4 ± 0.9 uv) and Fz (4.2 ± 0.9 uv), $ps < .001$, as well as a Stimulus main effect, $F = 129$, $p < .001$, $\eta_p^2 = .633$, with target stimulus eliciting larger amplitude compared with standard stimuli. These main effects were further superseded by a Stimulus x Electrode interaction, $F = 38.2$, $p < .001$, $\eta_p^2 = .338$, showing that the increased amplitude for target compared to standard stimuli at Pz (12.0 ± 1.0 uv) and Cz (10.6 ± 0.9 uv) were significantly greater compared to Fz (5.6 ± 0.8 uv), $ps < .001$.

Based on our visual inspection on the time-frequency plot (Figure 1.B), alpha ERD was observed at the Pz electrode between 700-1000ms after stimulus onset. This time window was used to calculate the averaged values in lower and upper alpha

frequency bands. The selection of the time-frequency representations of interest at Pz was confirmed by an Electrode main effect on both lower and upper alpha ERD (i.e., decreased power), $F_s > 9.8$, $ps < .001$, $\eta_p^2 > .116$, with Pz (lower: -0.778 ± 0.09 db; upper: -0.39 ± 0.10 db) showing greater ERD compared with Cz (lower: -0.466 ± 0.08 db ;upper: -0.23 ± 0.09 db) and Fz (lower: -0.221 ± 0.08 db; upper: -0.13 ± 0.08 db), $ps < .001$, as well as a Stimulus main effect, $F_s > 12$, $ps < .001$, $\eta_p^2 = .138$, with target (lower: -1.058 ± 0.147 db; upper: -0.518 ± 0.15 db) stimulus inducing greater ERD compared with standard (lower: 0.081 ± 0.043 db ;upper: 0.02 ± 0.05 db) stimuli. These main effects were further superseded by a Stimulus x Electrode interaction, $F_s < 12.8$, $ps < .001$, $\eta_p^2 < .146$, showing that the increased ERD from standard to target stimuli at Pz (lower: -1.786 ± 0.184 db; upper: -0.925 ± 0.193 db) was significantly greater compared to Cz (lower: -1.095 ± 0.171 db; upper: -0.457 ± 0.164 db) and Fz (lower: -0.537 ± 0.160 db; upper: -0.234 ± 0.162 db), $ps < .001$. Together, the observed P3 and alpha ERD specifically following the target stimulus at Pz replicated previous findings in older children and adults (Klimesch, 1999; Raine et al., 2018) and thus were used for subsequent analysis.

Correlation and Regression Analysis

As shown in Table 2, the bivariate correlation analysis showed that age was positively correlated with muscular power, muscular endurance, physical fitness, and motor competence as well as all task performance indices. Sex and creativity were not correlated with any variables. Muscular power, muscular endurance, physical fitness, and motor competence were positively associated with the task performance outcomes.

Most of the correlations remained significant in hierarchical regression analysis after controlling for age, with increased muscular power positively associating with hit rate, increased muscular endurance negatively associating with RT, and increased physical fitness associating with both improved hit rate and RT. Similarly, motor competence showed a beneficial association with all of the behavioral outcomes after controlling for age (see Table 3).

Bivariate correlation analysis (see Table 2) on neuroelectric indices showed that increased muscular endurance, physical fitness, and motor competence scores were associated with increased P3 amplitude and decreased upper alpha (i.e., greater upper alpha ERD), with increased motor competence showing an additional correlation with decreased lower alpha (i.e., greater lower alpha ERD). After controlling for age (see Table 3), increased muscular endurance was associated with increased P3 amplitude while higher physical fitness and motor competence scores were related to greater upper alpha ERD (i.e., decreased upper alpha). Further, these associations were particularly prominent at the parietal region base on the visual inspection on Figure 1.C.

Mediation Analysis

Given the observed associations of fitness and motor competence with neuroelectric indices and task performance and the previously reported associations between the neuroelectric and task performance outcomes (Yordanova et al., 2001), we first tested the correlations of P3 and alpha ERD indices with task performance measures, and found negative correlations between P3 amplitude and RT ($r = -.304$, $p = .008$) as well as positive correlations of lower alpha ERD ($r = -.239$, $p = .037$) and upper alpha ERD ($r = -.389$, $p = .001$) with RT. Subsequently, we conducted a

mediation analysis to test the extent to which the neuroelectric indices mediated the associations identified in the hierarchical regression analysis. The results revealed that P3 amplitude did not mediate the associations of muscular endurance, $B = -1.61$, $SE = 0.99$, 95%CI [-3.77, 0.02], physical fitness, $B = -3.32$, $SE = 2.15$, 95%CI [-8.18, 0.00], and motor competence, $B = -1.40$, $SE = 1.04$, 95%CI [-3.91, 0.07], with RT. However, upper alpha ERD mediated the association between physical fitness and RT, $B = -4.55$, $SE = 2.68$, 95%CI [-10.33, -0.05], as well as the association between motor competence and RT, $B = -2.35$, $SE = 1.55$, 95%CI [-5.86, -0.04], after controlling for age.

Discussion

The purpose of this study was to examine the associations of physical fitness and motor competence with behavioral and EEG indices during an auditory oddball task in preschool children. Specifically, we focused on P3 and alpha ERD because they not only reflect the engagement and disengagement of neural inhibition process that facilitates the allocation of attentional resources to the concurrent task (Polich, 2007; Yordanova et al., 2001) but may also manifest the development of neuroelectric mechanisms underlying attention networks (Riggins & Scott, 2020; Thorpe, Cannon, & Fox, 2016). The results showed beneficial associations of muscular endurance, physical fitness, and motor competence with task performance, P3 amplitude, and upper alpha ERD. Further, the beneficial associations of physical fitness and motor competence with response speed were mediated by upper alpha ERD. Collectively, the current study demonstrated that physical fitness and motor competence may play important roles for

cognitive performance and its neuroelectric correlates related to attention networks during the preschool years.

Replicating previous research in preschool children, physical fitness and motor competence were associated with better task performance outcomes. Although the auditory oddball paradigm is a discrimination task that has been primarily used to elicit P3 in young children (Riggins & Scott, 2020), increased hit rate and decreased RT during this task may reflect superior two-choice decision-making process relying on the stimulus categorization and response selection. The current results showed that physical fitness and motor competence were associated with both increased response accuracy and decreased RT. These findings are in line with previous studies showing beneficial associations of physical fitness (Niederer et al., 2011; Tsai et al., 2020) and motor competence (van der Fels et al., 2015; Wassenberg et al., 2005) with cognitive performance in preschool children. Further, differential associations of fitness domains with task performance were observed, with increases in muscular power and muscular endurance associating with higher hit rate and decreased RT, respectively, whereas balance and flexibility were not associated with any task performance outcomes. Collectively, the behavioral results suggest that increased motor competence and physical fitness, particularly muscular fitness, may be important for task performance requiring controlled attention in preschool children.

Beyond the covert behavioral outcomes, physical fitness and motor competence were associated with increased P3 amplitude, although such an association only remained for muscular endurance after controlling for age. This specific association suggests a unique role of muscular endurance in the neural inhibition process needed

to reallocate attentional resources. Developmentally, P3 is theorized as a neuroelectric marker of brain development, with P3 amplitude increasing from infancy to adolescence (Riggins & Scott, 2020). Neurologically, the origin of P3 stems from interactions between fronto-parietal regions (Kim, 2014; Polich, 2003; Soltani & Knight, 2000), which are important for the orienting and executive attention systems (Petersen & Posner, 2012). Thus, the observed association herein suggests the importance of muscular endurance for the neuroelectric function that is responsible for task-related attentional processes as well as reflects functional brain development underlying attention networks during early childhood.

Despite the lack of associations of physical fitness and motor competence with P3, they were related to greater parietal upper alpha ERD after controlling for age. Given that the alpha ERD was theorized as an indication of release from neural inhibition (Klimesch, 2012), the observed alpha ERD temporally (700-1000 ms post-stimulus) following P3 and behavioral responses may reflect a resetting process that updates mental representation in preparation for the upcoming task performance (Yordanova et al., 2001). Further, these associations were only found in the upper alpha band, suggesting that physical fitness and motor competence are beneficial for task-specific rather than general attentional processes (Klimesch, 1999). Results from the mediation analysis further demonstrated that upper alpha ERD mediated the associations of physical fitness and motor competence with response time during the auditory oddball task, suggesting a potential mechanistic role of the attentional process following stimulus evaluation to the associations of fitness and motor competence with task performance. Moreover, parietal upper alpha ERD has been associated with the

fronto-parieto-occipital attention system (Capotosto et al., 2009; Capotosto et al., 2017; Lenartowicz et al., 2016), which largely overlaps with the brain structure and connectivity that benefit from physical fitness (Esteban-Cornejo et al., 2017; Esteban-Cornejo et al., 2019; Talukdar et al., 2018) as well as the orienting and executive attention networks during early development (Petersen & Posner, 2012). Thus, the observed association of physical fitness and motor competence with upper alpha ERD may be a manifestation of superior development of these networks.

The current study is novel in that it is the first to use neuroelectric indices to examine the associations of fitness and motor competence with neurocognitive function in preschool children. Specifically, we focused on non-aerobic fitness domains and motor competence, which are important for the developmental and health outcomes (Robinson et al., 2015; Smith et al., 2014), yet less explored in preschoolers. Moreover, the mediation analysis provided the first evidence to support a potential mechanistic role of brain oscillations that mediate the beneficial association of physical fitness and motor competence with task performance.

Despite these strengths, the conclusions drawn from this study are limited due to its cross-sectional design. Future studies using a longitudinal design to examine the relations between developmental changes in physical fitness, motor competence, task performance, and EEG indices are needed to better understand the influences of early childhood physical and motor development on the developmental trajectory of cognitive and brain function. Further, the current findings related to overall physical fitness composite scores should be interpreted with caution because aerobic fitness was not included in the employed fitness test battery. Moreover, indicators of socioeconomic

status (i.e., parental education, family income) have been identified as potential confounding factors that have impacts on early brain maturation (Hair, Hanson, Wolfe, & Pollak, 2015). Future research including these variables is needed to determine the unique contribution of physical fitness and motor competence to cognitive and brain development in preschool children.

The current study showed that early childhood physical fitness and motor competence were associated with better task performance during an auditory attentional task. Further, Similar beneficial associations were also found with P3 and upper alpha ERD, with the upper alpha ERD being identified as a mediator of the associations of both physical fitness and motor competence with task response time. Given that these neuroelectric markers reflect effective neural inhibition necessary to facilitate attentional processes as well as superior brain development, the current findings suggest that physical fitness and motor competence during preschool may play important roles in facilitating brain development underlying attention and related behavioral outcomes. Such a finding has considerable implications as it informs the need to design early childhood programs that promote physical fitness and motor competence.

References

- Arnheim, D., Sinclair, W., & Sinclair, S. (1979). The basic motor ability tests-revised. *The clumsy child*, 119-144.
- Capotosto, P., Babiloni, C., Romani, G. L., & Corbetta, M. (2009). Frontoparietal cortex controls spatial attention through modulation of anticipatory alpha rhythms. *Journal of Neuroscience*, 29(18), 5863-5872.
- Capotosto, P., Baldassarre, A., Sestieri, C., Spadone, S., Romani, G. L., & Corbetta, M. (2017). Task and regions specific top-down modulation of alpha rhythms in parietal cortex. *Cerebral cortex*, 27(10), 4815-4822.
- Chang, Y. K., Tsai, Y. J., Chen, T. T., & Hung, T. M. (2013). The impacts of coordinative exercise on executive function in kindergarten children: An ERP study. *Experimental Brain Research*, 225(2), 187-196. doi:10.1007/s00221-012-3360-9
- Davis, E. E., Pitchford, N. J., & Limback, E. (2011). The interrelation between cognitive and motor development in typically developing children aged 4–11 years is underpinned by visual processing and fine manual control. *British Journal of Psychology*, 102(3), 569-584.
- Diamond, A. (2000). Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Development*, 71(1), 44-56.
- Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., . . . Szabo-Reed, A. N. (2016). Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review. *Med Sci Sports Exerc*, 48(6), 1197-1222. doi:10.1249/MSS.0000000000000901

Drollette, E. S., Pontifex, M. B., Raine, L. B., Scudder, M. R., Moore, R. D., Kao, S. C., . . . Castelli, D. M. (2018). Effects of the FITKids physical activity randomized controlled trial on conflict monitoring in youth. *Psychophysiology*, 55(3), e13017.

Durston, S., Davidson, M. C., Tottenham, N., Galvan, A., Spicer, J., Fossella, J. A., & Casey, B. (2006). A shift from diffuse to focal cortical activity with development. *Developmental science*, 9(1), 1-8.

Esteban-Cornejo, I., Cadenas-Sanchez, C., Contreras-Rodriguez, O., Verdejo-Roman, J., Mora-Gonzalez, J., Migueles, J. H., . . . Catena, A. (2017). A whole brain volumetric approach in overweight/obese children: Examining the association with different physical fitness components and academic performance. The ActiveBrains project. *NeuroImage*, 159, 346-354.

Esteban-Cornejo, I., Rodriguez-Ayllon, M., Verdejo-Roman, J., Cadenas-Sanchez, C., Mora-Gonzalez, J., Chaddock-Heyman, L., . . . Erickson, K. I. (2019). Physical fitness, white matter volume and academic performance in children: findings from the ActiveBrains and FITKids2 projects. *Frontiers in Psychology*, 10, 208.

Fuchs-Beauchamp, K. D., Karnes, M. B., & Johnson, L. J. (1993). Creativity and intelligence in preschoolers. *Gifted Child Quarterly*, 37(3), 113-117.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: a review using an integrative framework. *Psychological bulletin*, 134(1), 31.

Haapala, E., Lintu, N., Väistö, J., Tompuri, T., Soininen, S., Viitasalo, A., . . . Laitinen, T. (2019). Longitudinal associations of fitness, motor competence, and adiposity with cognition. *Medicine and Science in Sports and Exercise*, 51(3).

- Haapala, E. A., Lintu, N., Väistö, J., Robinson, L. E., Viitasalo, A., Lindi, V., & Lakka, T. A. (2015). Associations of physical performance and adiposity with cognition in children. *Medicine & Science in Sports & Exercise*, 47(10), 2166-2174.
- Hair, N. L., Hanson, J. L., Wolfe, B. L., & Pollak, S. D. (2015). Association of child poverty, brain development, and academic achievement. *JAMA pediatrics*, 169(9), 822-829.
- Hayes, A. F. (2017). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*: Guilford publications.
- Hillman, C. H., Buck, S. M., Themanson, J. R., Pontifex, M. B., & Castelli, D. M. (2009). Aerobic Fitness and Cognitive Development: Event-Related Brain Potential and Task Performance Indices of Executive Control in Preadolescent Children. *Developmental Psychology*, 45(1), 114-129. doi:10.1037/a0014437
- Hillman, C. H., Castelli, D. M., & Buck, S. M. (2005). Aerobic fitness and neurocognitive function in healthy preadolescent children. *Medicine and Science in Sports and Exercise*, 37(11), 1967-1974. doi:10.1249/01.mss.0000176680.79702.ce
- Hsieh, S. S., Chueh, T. Y., Morris, T. P., Kao, S. C., Westfall, D. R., Raine, L. B., . . . Kramer, A. F. (2020). Greater childhood cardiorespiratory fitness is associated with better top-down cognitive control: A midfrontal theta oscillation study. *Psychophysiology*, 57(12), e13678.
- Hsieh, S. S., Lin, C. C., Chang, Y. K., Huang, C. J., & Hung, T. M. (2017). Effects of Childhood Gymnastics Program on Spatial Working Memory. *Medicine and Science in Sports and Exercise*. doi:10.1249/mss.0000000000001399

Hudson, K. N., Ballou, H. M., & Willoughby, M. T. (2020). Improving motor competence skills in early childhood has corollary benefits for executive function and numeracy skills.

Developmental science, e13071.

Hung, C.-L., Chang, Y.-K., Chan, Y.-S., Shih, C.-H., Huang, C.-J., & Hung, T.-M. (2013). Motor ability and inhibitory processes in children with ADHD: a neuroelectric study. *Journal of Sport and Exercise Psychology*, 35(3), 322-328.

Jensen, O., & Mazaheri, A. (2010). Shaping functional architecture by oscillatory alpha activity: gating by inhibition. *Frontiers in Human Neuroscience*, 4, 186.

Kao, S.-C., Drollette, E. S., Scudder, M. R., Raine, L. B., Westfall, D. R., Pontifex, M. B., & Hillman, C. H. (2017). Aerobic fitness is associated with cognitive control strategy in preadolescent children. *Journal of motor behavior*, 49(2), 150-162.

Kao, S. C., Cadenas-Sanchez, C., Shigeta, T. T., Walk, A. M., Chang, Y. K., Pontifex, M. B., & Hillman, C. H. (2020). A systematic review of physical activity and cardiorespiratory fitness on P3b. *Psychophysiology*, 0(0), e13425. doi:10.1111/psyp.13425

Kao, S. C., Westfall, D. R., Parks, A. C., Pontifex, M. B., & Hillman, C. H. (2017). Muscular and Aerobic Fitness, Working Memory, and Academic Achievement in Children. *Med Sci Sports Exerc*, 49(3), 500-508. doi:10.1249/MSS.0000000000001132

Keye, S. A., Walk, A. M., Cannavale, C. N., Iwinski, S., McLoughlin, G. M., Steinberg, L. G., & Khan, N. A. (2021). Six-Minute Walking Test Performance Relates to Neurocognitive Abilities in Preschoolers. *Journal of clinical medicine*, 10(4), 584.

Kim, H. (2014). Involvement of the dorsal and ventral attention networks in oddball stimulus processing: A meta-analysis. *Human brain mapping*, 35(5), 2265-2284.

- Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain research reviews*, 29(2-3), 169-195.
- Klimesch, W. (2012). Alpha-band oscillations, attention, and controlled access to stored information. *Trends in Cognitive Sciences*, 16(12), 606-617.
- Klimesch, W., Doppelmayr, M., Röhme, D., Pöllhuber, D., & Stadler, W. (2000). Simultaneous desynchronization and synchronization of different alpha responses in the human electroencephalograph: a neglected paradox? *Neuroscience Letters*, 284(1-2), 97-100.
- Lenartowicz, A., Lu, S., Rodriguez, C., Lau, E. P., Walshaw, P. D., McCracken, J. T., . . . Loo, S. K. (2016). Alpha desynchronization and frontoparietal connectivity during spatial working memory encoding deficits in ADHD: A simultaneous EEGfMRI study. *NeuroImage: Clinical*, 11, 210-223.
- Mora-Gonzalez, J., Esteban-Cornejo, I., Cadenas-Sanchez, C., Migueles, J. H., Rodriguez-Ayllon, M., Molina-García, P., . . . Ortega, F. B. (2019). Fitness, physical activity, working memory, and neuroelectric activity in children with overweight/obesity. *Scandinavian Journal of Medicine & Science in Sports*, 29(9), 1352-1363.
- Mulvey, K. L., Taunton, S., Pennell, A., & Brian, A. (2018). Head, toes, knees, SKIP! Improving preschool children's executive function through a motor competence intervention. *Journal of Sport and Exercise Psychology*, 40(5), 233-239.
- Niederer, I., Kriemler, S., Gut, J., Hartmann, T., Schindler, C., Barral, J., & Puder, J. J. (2011). Relationship of aerobic fitness and motor skills with memory and attention in preschoolers (Ballabeina): a cross-sectional and longitudinal study. *BMC pediatrics*, 11(1), 1-9.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, 35, 73-89.

Polich, J. (2003). *Detection of change: event-related potential and fMRI findings*: Springer.

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical Neurophysiology*, 118(10), 2128-2148.

Pontifex, M. B., Raine, L. B., Johnson, C. R., Chaddock, L., Voss, M. W., Cohen, N. J., . . . Hillman, C. H. (2011). Cardiorespiratory fitness and the flexible modulation of cognitive control in preadolescent children. *Journal of Cognitive Neuroscience*, 23(6), 1332-1345.
doi:10.1162/jocn.2010.21528

Posner, M. I., Rothbart, M. K., Sheese, B. E., & Voelker, P. (2012). Control networks and neuromodulators of early development. *Developmental Psychology*, 48(3), 827.

Raine, L. B., Kao, S.-C., Pindus, D., Westfall, D. R., Shigeta, T. T., Logan, N., . . . Pontifex, M. B. (2018). A large-scale reanalysis of childhood fitness and inhibitory control. *Journal of Cognitive Enhancement*, 2(2), 170-192.

Riggins, T., & Scott, L. S. (2020). P300 development from infancy to adolescence. *Psychophysiology*, 57(7), e13346.

Robinson, L. E., Stodden, D. F., Barnett, L. M., Lopes, V. P., Logan, S. W., Rodrigues, L. P., & D'Hondt, E. (2015). Motor competence and its effect on positive developmental trajectories of health. *Sports medicine*, 45(9), 1273-1284.

Rothbart, M. K., Sheese, B. E., Rueda, M. R., & Posner, M. I. (2011). Developing mechanisms of self-regulation in early life. *Emotion review*, 3(2), 207-213.

Smith, J. J., Eather, N., Morgan, P. J., Plotnikoff, R. C., Faigenbaum, A. D., & Lubans, D. R. (2014).

The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. *Sports Med*, 44(9), 1209-1223. doi:10.1007/s40279-014-0196-4

Soltani, M., & Knight, R. T. (2000). Neural origins of the P300. *Critical Reviews™ in Neurobiology*, 14(3-4).

Talukdar, T., Nikolaidis, A., Zwillling, C. E., Paul, E. J., Hillman, C. H., Cohen, N. J., . . . Barbey, A. K. (2018). Aerobic fitness explains individual differences in the functional brain connectome of healthy young adults. *Cerebral cortex*, 28(10), 3600-3609.

Thorpe, S. G., Cannon, E. N., & Fox, N. A. (2016). Spectral and source structural development of mu and alpha rhythms from infancy through adulthood. *Clinical Neurophysiology*, 127(1), 254-269.

Torrance, E. P. (1981). Predicting the Creativity of Elementary School Children (1958-80)—and the Teacher Who "Made a Difference". *Gifted Child Quarterly*, 25(2), 55-62.

Tsai, Y.-J., Huang, C.-J., Hung, C.-L., Kao, S.-C., Lin, C.-F., Hsieh, S.-S., & Hung, T.-M. (2020). Muscular fitness, motor competence, and processing speed in preschool children. *European Journal of Developmental Psychology*, 17(3), 415-431.

Tsai, Y.-J., Hung, C.-L., Tsai, C.-L., Chang, Y.-K., Huang, C.-J., & Hung, T.-M. (2017). The relationship between physical fitness and inhibitory ability in children with attention deficit hyperactivity disorder: An event-related potential study. *Psychology of Sport and Exercise*, 31, 149-157.

- Utesch, T., Bardid, F., Büsch, D., & Strauss, B. (2019). The relationship between motor competence and physical fitness from early childhood to early adulthood: A meta-analysis. *Sports medicine*, 49(4), 541-551.
- van der Fels, I. M., Te Wierike, S. C., Hartman, E., Elferink-Gemser, M. T., Smith, J., & Visscher, C. (2015). The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: A systematic review. *Journal of science and medicine in sport*, 18(6), 697-703.
- van Dinteren, R., Arns, M., Jongsma, M. L., & Kessels, R. P. (2014). P300 development across the lifespan: a systematic review and meta-analysis. *PLOS ONE*, 9(2), e87347.
- Wang, C. H., Shih, C. M., & Tsai, C. L. (2016). The Relation Between Aerobic Fitness and Cognitive Performance Is it Mediated by Brain Potentials? *Journal of Psychophysiology*, 30(3), 102-113. doi:10.1027/0269-8803/a000159
- Wassenberg, R., Feron, F. J., Kessels, A. G., Hendriksen, J. G., Kalff, A. C., Kroes, M., . . . Vles, J. S. (2005). Relation between cognitive and motor performance in 5-to 6-year-old children: Results from a large-scale cross-sectional study. *Child Development*, 76(5), 1092-1103.
- Wick, K., Kriemler, S., & Granacher, U. (2021). Effects of a Strength-Dominated Exercise Program on Physical Fitness and Cognitive Performance in Preschool Children. *The Journal of Strength & Conditioning Research*.
- Yordanova, J., Kolev, V., & Polich, J. (2001). P300 and alpha event-related desynchronization (ERD). *Psychophysiology*, 38(1), 143-152.

Table 1. The mean and standard deviation of demographic, fitness, and cognitive measures

Measure	Boys (N = 49)	Girls (N = 27)	All (N = 76)
Age (month)	68.1 ± 3.9	68.9 ± 6.2	68.4 ± 4.8
Creativity (score)	105 ± 70	79.1 ± 69.9	96.3 ± 70.6
Stand long jump (centimeter)	101.6 ± 15.0	98.4 ± 19.7	100.5 ± 16.8
60-second sit-up (repetition)	7.2 ± 4.7	7.3 ± 4.9	7.2 ± 4.7
Single-leg stand (second)	3.5 ± 2.9	4.0 ± 2.6	3.7 ± 2.8
Sit-and-reach (centimeter)	22.7 ± 6.4	24.8 ± 5.5	23.4 ± 6.2
Bead stringing (number)	8.9 ± 2.4	8.7 ± 2.1	8.8 ± 2.3
Target throwing (score)	5.5 ± 1.6	4.8 ± 2.0	5.2 ± 1.8
Marble transfer (number)	12.9 ± 3.9	21.2 ± 6.1	16.6 ± 6.3
Basketball throw for distance (centimeter)	111.5 ± 41.4	75.0 ± 38.9	96.3 ± 44.0
Kicking ball (score)	6.4 ± 4.1	6.3 ± 2.6	6.4 ± 3.5
Static balance (second)	83.3 ± 81.9	97.2 ± 118.5	89.0 ± 98.3
Prone-stand-turn position (number)	7.9 ± 2.7	4.7 ± 1.2	6.6 ± 2.7
Ball striking (score)	10.3 ± 9.8	9.3 ± 7.6	9.9 ± 8.9
Agility (second)	7.3 ± 0.9	7.7 ± 1.0	7.5 ± 1.0
Hit (percent correct)	92.7 ± 7.3	91.1 ± 9.0	92.1 ± 7.9
FA (percent correct)	3.0 ± 2.5	2.5 ± 1.6	2.8 ± 2.2
<i>d'</i>	3.6 ± 0.7	3.5 ± 0.7	3.6 ± 0.7
RT (millisecond)	574 ± 88	615 ± 158	589 ± 118
P3 amplitude (microvolt)	16.1 ± 9.2	14.8 ± 7.0	15.6 ± 8.5
P3 latency (millisecond)	644 ± 120.8	615 ± 118	633 ± 120
Lower Alpha ERD (decibel)	-1.9 ± 1.5	-1.8 ± 1.5	-1.67 ± 1.5
Upper Alpha ERD (decibel)	-0.9 ± 1.5	-0.7 ± 1.7	-0.85 ± 1.6

Table 2. Bivariate correlations between demographic, fitness, and cognitive variables

	Age	Sex	Create	Power	Endure	Flexi	Balan	Fitness	Motor
Age	-	.082	-.082	.309*	.266*	-.154	.108	.272*	.405*
Sex	-	-	-.178	-.094	.006	.165	.071	.069	-.062
Creativity	-	-	-	.063	-.077	-.173	-.007	-.099	-.088
Hit	.237*	-.096	-.076	.336*	.219	.105	.136	.406*	.504*
FA	-.261*	-.104	.050	-.047	-.04	.136	.101	.068	-.106
<i>d'</i>	.231*	-.026	-.011	.256*	.159	-.021	.005	0.21	.381*
RT	-.385*	.188	-.197	-.303*	-.333*	.079	-.078	-.326*	-.476*
P3 amplitude	.102	-.071	-.068	.216	.306*	.034	-.096	.250*	.242*
P3 latency	-.068	-.119	-.103	-.019	.002	.161	-.12	0.02	.023
Lower Alpha	-.158	-.083	-.024	-.205	-.169	-.070	.069	-.202	-.253*
Upper Alpha	-.163	.050	.087	-.234*	-.148	-.086	-.074	-.277*	-.325*

* denotes significant correlation at $p < 0.05$. Create = creativity. Endure = Endurance, Flexi = Flexibility, Balan = Balance.

Table 3. The summary of hierarchical regression analysis for behavioral and neuroelectric indices

	<i>Step 1</i>	<i>Step 2</i>				
	<i>R²</i>	<i>ΔR²</i>	<i>F</i>	<i>B</i>	<i>SE B</i>	<i>Beta</i>
Muscular Power						
Hit	.056*	.076*	5.59*	2.28	0.899	0.291*
d'	.053*	.038	3.66*	0.04	0.079	0.205
RT	.148*	.029	7.88*	-21.05	13.048	-0.180
Upper Alpha	.022	.029	1.96	-0.01	0.010	-0.178
Muscular Endurance						
RT	.148*	.057*	9.44*	-6.17	2.689	-0.248*
P3 amplitude	.010	.084*	3.79*	0.53	0.205	0.300*
Physical Fitness						
Hit	.056*	.126*	8.12*	1.51	0.451	0.368*
RT	.148*	.053*	9.18*	-14.61	6.650	-0.239*
P3 amplitude	.010	.053*	2.49	1.05	0.515	0.240*
Upper Alpha	.027	.059*	3.40*	-0.21	0.097	-0.251*
Motor Competence						
Hit	.056*	.199*	12.53*	0.977	0.221	0.488*
d'	.053*	.099*	6.55*	0.059	0.020	0.344*
RT	.148*	.123*	13.56*	-11.430	3.262	-0.383*
P3 amplitude	.010	.048	2.27	0.512	0.265	0.240
Lower Alpha	.025	.043	2.65	-0.085	0.046	-0.226
Upper Alpha	.027	.080*	4.37*	-0.126	0.049	-0.310*

Age was entered into Step 1 for all models. * denotes significant correlation at $p < 0.05$. Bolded values denote significant F test at $p < 0.05$ for the step 2.

Figure 1. P3-ERP and alpha ERD during the auditory oddball task and their associations with muscular endurance, physical fitness, and motor competence. (A) The ERP grand average waves show a P3 peaked around 650 ms after the onset of target stimulus at the Pz electrode while a much weaker P3 was observed following standard stimulus. (B) The time-frequency representation of oscillatory activities shows a desynchronization of both lower (8 – 10) Hz and higher (10 – 12 Hz) alpha frequency from 700 – 1000 ms at the Pz electrode following the onset of target (right) but not standard (left) stimulus. (C) The topographical distribution of the R^2 changes for each electrode obtained from the second step of the hierarchical regression analysis on the association of muscular endurance with P3 elicited by target stimulus and the associations of physical fitness and motor competence with upper alpha ERD elicited by target stimulus.