Motor Ability and Inhibitory Processes in Children With ADHD: A Neuroelectric Study

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The purpose of the current study was to examine the relationship between motor ability and response inhibition using behavioral and electrophysiological indices in children with ADHD. A total of 32 participants were recruited and underwent a motor ability assessment by administering the Basic Motor Ability Test-Revised (BMAT) as well as the Go/No-Go task and event-related potential (ERP) measurements at the same time. The results indicated that the BMAT scores were positively associated with the behavioral and ERP measures. Specifically, the BMAT average score was associated with a faster reaction time and higher accuracy, whereas higher BMAT subset scores predicted a shorter P3 latency in the Go condition. Although the association between the BMAT average score and the No-Go accuracy was limited, higher BMAT average and subset scores predicted a shorter N2 and P3 latency and a larger P3 amplitude in the No-Go condition. These findings suggest that motor abilities may play roles that benefit the cognitive performance of ADHD children.

Keywords: cognition, event-related potential, executive control, go/no-go task, inhibition

Attention-deficit hyperactivity disorder (ADHD) is one of the most common psychiatric disorders among children; it affects approximately 3–7% of school-aged children. The disorder-related syndromes are associated with a variety of problems, including cognitive deficits, poor academic performance, and impairment in social functioning (Biederman, 2005). Up to 50% of children with ADHD have motor difficulties (Slaats-Willemse, de Sonneville, Swaab-Barneveld, & Buitelaar, 2005). Several studies demonstrated that children with ADHD were more likely to suffer from deficits in performing fine motor movements (Piek, Pitcher, & Hay, 1999). These deficits are manifested in poor performance on tasks that demand complex movements, including copying, maze tracking, and pursuit tracking (Mariani & Barkley, 1997; Sergeant, Piek, & Oosterlaan, 2006). Common mechanisms associated with the cognitive deficits and motor difficulties of children with ADHD, including the involvement of several brain structures and neurotransmitter systems, have been identified. Motor cortical regions of the frontal cortex, basal ganglia, and cerebellum, which are highly involved in the acquisition and/or consolidation of skilled motor behaviors, are rich in dopaminergic pathways (Halsband & Lange, 2006; Luft & Buitrago, 2005). A possible link between cognitive and motor deficits in ADHD is supported by several studies. Waber and Bernstein (1994) demonstrated a relationship between complex motor skills and inhibition using a repeated pattern test. Moreover, upon evaluating neurophysiological data, Band and van Boxtel (1999) concluded that inhibitory effects involved in cognitive and motor control processes occurred upstream of or in the motor cortex.

According to the model of ADHD proposed by Barkley (1997), inhibition is regarded as the ability to withhold a response to an event, stop an ongoing response, and resist or control interference (Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009). Studies using the Go/No-Go task found that ADHD subjects showed worse performance and slower reaction times.
than normal subjects (Johnstone et al., 2009). Alternatively, event-related potentials (ERPs) can be used to study the underlying neural mechanisms of inhibitory processes in ADHD individuals with a high degree of temporal resolution. For example, the N2 component of ERP has been suggested to indicate the inhibition of the prepotent response in the No-Go condition (Lavric, Pizzagalli, & Forstmeier, 2004). In contrast, the P3 component is thought to be involved in several processes, including stimulus evaluation, resource allocation, and cortical inhibition (Brandeis et al., 1998). In addition, a larger P3 amplitude reflects increased attention toward a stimulus, and a shorter P3 latency is considered to reflect a faster stimulus evaluation process (Hillman, Kamijo, & Scudder, 2011). Significant differences in both N2 and P3 between ADHD individuals and their matched controls when performing the Go/No-Go task have been reported. Studies have shown that ADHD subjects have smaller P3 amplitudes and longer N2 and P3 latencies than their counterparts (Fisher, Aharon-Peretz, & Pratt, 2011; Johnstone et al., 2009), suggesting some processes of inhibition are impaired in individuals with ADHD.

Because children with ADHD are impaired in both motor abilities and inhibitory capacity and these impairments may have a common neurophysiological basis, a relationship between these two dimensions of behavior might be expected. Previous studies have shown a potential benefit of physical activity on cognition in children with ADHD. Gapin and Etnier (2010) examined the relationship between physical activity and executive function in children with ADHD and found that moderate-to-vigorous physical activity (MVPA) could significantly predict the planning ability, as assessed by the Tower of London task, in children with ADHD whereas the association between physical activity and other executive functions, such as inhibition, working memory, and processing speed, was in the expected direction but not significantly different. Smith et al. (2013) further investigated the beneficial effect of physical activity on cognitive, motor, social, and behavioral functioning measures by administering 8 weeks of MVPA intervention to young children with hyperactivity/impulsivity symptoms. Several measures showed significant or marginally significant improvements after the program, with small to medium effect sizes. Notably, the most consistently favorable findings were associated with response inhibition, suggesting that physical activity may be particularly helpful in addressing the essential symptoms of ADHD.

Although a few studies have suggested potential links between physical activity, exercise intervention, and multiple components of cognition, to the best of our knowledge, no existing study has specifically explored the relationship between motor ability and inhibitory function at the electrophysiological level in ADHD. Therefore, the purpose of the current study was to examine the relationship between electrophysiological and behavioral indices of response inhibition and motor abilities in children with ADHD. We predicted that better motor ability performance would be associated with better performance in the Go/No-Go task.

**Method**

**Participants**

A total of 32 children (mean age = 8.95 ± 1.29 years) were included in the final analysis. The participants had been previously diagnosed as having ADHD by medical professionals; only right-handed children who were reported to be free of neurological disorders were eligible to participate in the current study. All children were instructed to be free of medications and behavioral treatment for at least 24 hr before participation in the experiment. The children and their parents completed a written assessment and gave informed consent. This study was approved by the Institutional Review Board at National Taiwan Sport University.

**Motor Ability Assessment**

The participants’ motor abilities, indexed here, were assessed using the Basic Motor Ability Test–Revised (BMAT), a motor ability test designed specifically for children between 4 and 12 years old (Arnheim & Sinclair, 1979). The BMAT includes seven subtests to reflect different abilities: a basketball throw for distance (to test arm and shoulder girdle explosive strength), bead stringing (to test bilateral eye–hand coordination and dexterity), target throwing (to test eye–hand coordination associated with throwing), marble transfer (to test finger dexterity), back and hamstring stretch (to test the flexibility of the back and hamstring muscles), a standing long jump (to test the strength and power in the thigh and lower leg muscles), and ball striking (to test coordination associated with striking). The test–retest reliability for the BMAT was 0.93 (Arnheim & Sinclair, 1979).

**Go/No-Go Task**

The computerized Go/No-Go task created with NeuroScan Stim software (Version 2.0) incorporates three stimuli: the warning/cue stimulus (S1), a yellow square; the response stimulus (Go, S2), a green circle; and the No-response stimulus (No-Go, S2), a red octagon. These stimuli were presented as 3- × 3-cm figures at a 2.87° visual angle in the center of a computer screen on a black background. During the performance of the task, the participants were instructed to first watch the central fixation cross on the computer screen. They were then required to execute a button press with their right index finger as quickly and accurately as possible to respond to the Go stimulus (the Go stimulus occurred with 70% probability) and to withhold a response for a No-Go stimulus (the No-Go stimulus occurred with 30% probability).

Each trial began with the presentation of the S1 warning cue for 500 ms, followed by an interval of 1500 ms;
the S2 imperative stimulus was then presented for 200 ms. The next trial started 500 ms after the button-press response was made or at the end of the response window of 1000 ms from S2. The Go/No-Go task consisted of eight blocks; each block had 20 trials (14 Go trials and 6 No-Go trials). The participants performed all blocks with 1-min breaks. The total duration of the Go/No-Go task was approximately 16 min.

**Electroencephalogram**

Electroencephalographic (EEG) activity was measured using a NeuroScan Quik-Cap (Neuro, Inc., Charlotte, NC, USA). An average of the mastoid (A1, A2) served as a reference, with AFz set as the ground electrode. To monitor possible artifacts due to eye movements, electro-oculographic (EOG) activity was also collected from electrodes placed above and below the left orbit and at the outer canthus of each eye to record bipolar eye movements. Impedance was maintained below 10 kΩ. Continuous data were digitized at a sampling rate of 500 Hz with a DC to 100-Hz filter, and a 60-Hz notch filter was applied using a Neuroscan NuAmps amplifier.

Offline data from the continuous EEG data were merged with the behavioral data. Ocular artifacts were corrected using an algorithm to minimize eye movement artifacts in the EEG signals. Epochs were defined as 100 ms prestimulus to 900 ms poststimulus. Baseline correction was conducted using the 100-ms prestimulus interval. The data were filtered with a 30-Hz low-pass cutoff (12 dB/octave). Only correct responses to the Go and No-Go trials were included, and ERP trials with amplitudes outside the range of ±100 μV were excluded from further analysis. The N2 component of the ERP was defined as the maximal negative peak within 200–420 ms, and the P3 component was the maximal positive peak within 300–700 ms. The average number of trials was 48 ± 9.46 (35.07 ± 7.77 for the Go and No-Go tasks, respectively). Lastly, ERPs with artifact-free data from the Go and No-Go trials were further averaged separately at the midline sites (Fz, Cz, and Pz) for the statistical analysis.

**Experimental Procedures**

Each participant was invited to the laboratory on one occasion. In Session 1, the participant and his or her parent completed the informed consent and the health and demographics questionnaires. Then, the participant was seated in a comfortable chair in front of a computer screen, at a distance of 60 cm from the computer screen, and fitted with an electrode cap for the EEG measurements. The formal recording was started when the participant met the criteria of 80% correct responses in a 10-practice trial.

Following the completion of the Go/No-Go task and the ERP measurements, each participant was instructed to complete the motor ability assessment. The testing followed the BMAT guidelines (Arnheim & Sinclair, 1979) and was monitored by a trained examiner during the assessment. After completing the two sessions, the participants and their parents received $20 as compensation for their traveling expenses. Brief explanations of the project were then provided.

**Statistical Analysis**

The seven subsets of the BMAT were converted into standardized z-scores (indexed as the BMAT subset score), and the BMAT average score was computed as the average of the scores on these subsets (indexed as the BMAT average score). Pearson product–moment correlations were first used to determine the relationships among the BMAT average score, behavioral performance, and ERPs. For illustrative purposes, an independent t test was further conducted for the effect of high and low BMAT average scores (based upon the median split) on behavioral parameters, including reaction time (RT) and accuracy, and on ERP measures, including N2 and P3 in both the Go and No-Go conditions.

To test the hypothesis that motor ability could predict the behavioral data and ERPs, multiple regression analyses were further computed separately. These analyses examined the predictions of the seven BMAT subsets regarding both behavioral performance and ERPs while controlling age as a confounding variable. The adjusted \( r^2 \) and the highest beta coefficients are presented for interpreting the overall variance and the associations between factors. Collinearity is considered as acceptable when the VIF is less than 3. All statistical analyses were performed using SPSS 17.0; the significance level was set at \( p < .05 \).

**Results**

**Behavioral Measurements**

The task condition comparisons using paired t tests revealed that the No-Go condition had a lower accuracy (88.33 ± 9.84) than the Go condition (95.07 ± 6.25), \( t(31) = 3.21, p < .003 \). The correlation analysis revealed that the BMAT average score was negatively associated with Go RT and positively associated with Go accuracy, suggesting that participants with a better BMAT average score had better Go performances but that the BMAT average score had no significant correlation with the No-Go accuracy (Table 1).

Regarding the comparison between high and low BMAT average scores based upon a median split, compared with a low BMAT average score, a high BMAT average score was associated with a significantly faster RT (\( M = 506.80 ± 89.08 \) ms vs. \( 424.84 ± 100.29 \) ms) and higher Go response accuracy (\( M = 92.34\% \) vs. \( 97.81\% \)), \( t(30) > -3.98, p < .02 \). However, there was no significant effect of the BMAT average score on the No-Go response accuracy.

After adjusting for age, multiple regression analysis in the Go condition revealed that the BMAT subset scores significantly predicted the Go RT with an adjusted \( r^2 \) of .30 for the model, indicating that, overall, the subsets of BMAT explained 30% of the total variance, \( F(8, 23) = 2.65, p < .05 \). Further analysis revealed that the bas-
ketball throw for distance had the highest standardized beta coefficient (−.39, p = .07), with better basketball throws associated with shorter Go RTs. Similarly, multiple regression analysis revealed that Go accuracy was marginally significantly predicted with an adjusted $r^2$ of .23 for the model, suggesting that the BMAT subset score explained 23% of the total variance, $F(8, 23) = 2.18, p < .07$, where the basketball throw for distance had the highest and most significant standardized beta coefficient (.43, p = .05). However, the BMAT subset scores failed to predict the No-Go accuracy.

**ERP Measurements**

Specific ERP indices were computed as the average from the values at the middle sites (Fz, Cz, and Pz). The correlation analysis indicated that a better BMAT average score was significantly associated with shorter N2 and P3 latencies and that a better BMAT average score was associated with a smaller N2 amplitude in the Go condition. In addition, the BMAT average score was significantly associated with P3, with a better BMAT average score associated with shorter P3 latencies and larger P3 amplitudes, in the No-Go condition (Table 1).

When participants with high and low BMAT average scores were compared, the results indicated that no differences compared with the BMAT average score were found for the ERPs in the Go condition; however, compared with a low BMAT average score, a high BMAT average score had a significantly shorter N2 No-Go latency ($M = 346.67 \pm 27.74$ vs. $319.83 \pm 29.20$ ms) and shorter P3 No-Go latency ($M = 547.46 \pm 58.64$ vs. $480.00 \pm 68.36$ ms), $t(30) > -3.98, p < .02$ (Figure 1).

Regarding the N2 latency, after adjusting for age, the multiple regression analysis revealed that the BMAT subset score did not predict N2 latency in the Go condition. In contrast, the BMAT subset score significantly predicted N2 latency with an adjusted $r^2$ of .41 for the model in the No-Go condition; the BMAT subset score explained 41% of the total variance, $F(8, 23) = 3.69, p < .01$. Further analysis revealed that the basketball throw for distance and ball striking had the highest standardized beta coefficients (from −0.35 to −0.38), with marginally significant values (p ranging from .04 to .06), suggesting that better performance was associated with a shorter N2 latency. No significant differences between the BMAT subset score and N2 amplitude were found in either the Go or No-Go condition.

Regarding the P3 latency, the multiple regression analysis in the Go condition revealed that the BMAT subset score significantly predicted the P3 latency with an adjusted $r^2$ of .24 for the model; the BMAT subset score explained 24% of the total variance, $F(8, 23) = 2.21, p < .07$. However, further analysis revealed that the BMAT subset score had a limited association with the P3 latency in the Go condition. In contrast, the multiple regression analysis in the No-Go condition showed that the BMAT subset score significantly predicted the P3 latency with an adjusted $r^2$ of .58 for the model; the BMAT subset score explained 58% of the total variance, $F(8, 23) = 6.26, p < .001$. Further analysis revealed that the basketball throw for distance and bead stringing had the highest standardized beta coefficients (from −0.46 to −0.52) with significant values (p < .01), suggesting that better basketball throw and bead stringing performances were associated with a shorter P3 latency.

Regarding the P3 amplitude, although the BMAT subset score showed a nonsignificant prediction in the Go condition, the multiple regression analysis in the No-Go condition showed that the BMAT subset score significantly predicted the P3 amplitude with an adjusted $r^2$ of .27 for the model, indicating that the BMAT subset score explained 27% of the total variance, $F(8, 23) = 2.44, p < .05$. Further analysis revealed that the basketball throw for

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**Table 1 Correlation Matrix for Avg. BMAT, Behavioral Measures and ERPs**

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*Note.* BMAT avg. = BMAT average score, Go = Go condition, Ng = No-Go condition, Acc = Accuracy, N2L = N2 latency, N2A = N2 amplitude, P3L = P3 latency, P3A = P3 amplitude.

*p < .05; **p < .01.
distance and bead stringing had the highest standardized beta coefficients (0.51) with significant values ($p = .02$), suggesting that better performances were associated with a larger P3 amplitude.

**Discussion**

The primary results indicated that the BMAT outcome was positively associated with several measures at the behavioral and neuroelectric levels. Specifically, the BMAT average score was associated with a faster RT and higher accuracy. In addition, a higher BMAT subset score, particularly on the basketball throw for distance, predicted a shorter P3 latency in the Go condition. Although the association between the BMAT average score and No-Go accuracy was limited, the higher BMAT average score and the BMAT subset score, particularly on the basketball throw for distance, showed shorter N2 and P3 latencies and a larger P3 amplitude in the No-Go condition.

Regarding the Go condition, participants with high BMAT average scores had significantly higher accuracy and faster RTs compared with those with low BMAT average scores. In addition, the basketball throw for distance
variables among preschool children (Planinsec, 2002). The previous study showed that several motor abilities, including coordination, movement speed, balance, and explosive strength, are significantly associated with cognitive performance in children with ADHD (Planinsec, 2002).

Motor ability could be a possible line of exploration in seeking ways to improve cognitive performance, especially in children with ADHD. The majority of research studies on motor activity and cognitive performance have found beneficial effects of cardiovascular fitness and/or physical activity on the cognitive performance of elderly persons (Colcombe & Kramer, 2003) and children (Tomporowski, Davis, Miller, & Naglieri, 2008); some of these studies extended to special populations, such as children with ADHD (Gapin & Etnier, 2010; Halperin, Bédard, & Curchack-Lichtin, 2012; Smith et al., 2013). Nevertheless, motor abilities remain unexplored and may be associated with a great potential to improve cognitive performance in ADHD. Programs designed to improve motor abilities in ADHD have also led to observable improvements in other domains. For example, Banaschewski, Besmans, Zieger, and Rothenberger (2001) found that a four-month period of sensorimotor training could reduce hyperactivity and anxious-depressive/aggressive behavior in children with ADHD. Although the cognitive performance of children with ADHD was not directly measured in their study, improvement in inhibitory control can be inferred from the observed reductions in hyperactivity and other destructive behaviors.

Our finding should be interpreted with caution. The possibility that the observed positive association between motor ability and inhibitory control may be due to differences in the seriousness of the ADHD symptoms among the children in the study is difficult to exclude. Moreover, by using a cross-sectional design, a causal relationship between motor ability and cognitive function could not be established. Nevertheless, our work provides a solid foundation for future investigations that apply longitudinal interventions. Third, in the results reported here, $r^2$ was low to moderate, ranging from 0.23 to 0.58, suggesting that other factors were involved in the observed relationships. Given that Castelli and Valley (2007) found that children with better motor abilities may have higher levels of physical activity and/or fitness, which are associated with better cognitive performance, our results might be confounded with these factors, thereby limiting our interpretation by not including measures of physical activity and aerobic fitness.

Despite the limitations mentioned above, to our knowledge, the current study is the first to examine the relationship between motor ability and inhibitory control in children with ADHD using a neuroelectric approach. Our results demonstrate that motor abilities, particularly explosive strength and coordination, could play roles in the cognitive performance of ADHD children. In addition, the shorter latency of the N2 component and the larger amplitude and shorter latency of the P3 component are also consistent with the behavioral measures, indicating that ADHD children with better motor abilities exhibit better inhibitory control than their counterparts with worse motor abilities. These results shed light on the potential for alternative or adjuvant treatments for ADHD that can overcome the disadvantages of stimulant medication for the primary treatment of ADHD.
References


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