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From ERPs to academics

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ABSTRACT

Standardized tests have been used to forecast scholastic success of school-age children, and have been related to intelligence, working memory, and inhibition using neuropsychological tests. However, ERP correlates of standardized achievement have not been reported. Thus, the relationship between academic achievement and the P3 component was assessed in a sample of 105 children during performance on a Go/NoGo task. The Wide Range Achievement Test – 3rd edition was administered to assess aptitude in reading, spelling, and arithmetic. Regression analyses indicated an independent contribution of P3 amplitude to reading and arithmetic achievement beyond the variance accounted for by IQ and school grade. No such relationship was observed for spelling. These data suggest that the P3, which reflects attentional processes involved in stimulus evaluation and inhibitory control may be a biomarker for academic achievement during childhood.

1. Introduction

Standardized tests are often used to forecast scholastic success from early childhood through vocational, graduate, and professional studies (Kuncel and Hezlett, 2007; Kuncel et al., 2004). In secondary education, federal initiatives have placed external pressures on schools to provide students with basic competencies in traditional academic subject matter (e.g., mathematics, reading, science). Such competencies are monitored via standardized tests to determine educational program effectiveness, funding appropriations, and student academic placement. Accordingly, the quantification and prediction of academic success is appealing for a number of reasons.

Researchers focused on education have long been interested in the underlying cognitive processes that comprise scholastic performance (Bull et al., 2008; Diamond et al., 2007). Several component cognitive processes have demonstrated considerable relatedness with academic achievement including general cognitive ability (Rohde and Thompson, 2007), intelligence (Jensen, 1998), and processing speed (Jensen, 1992), as well as aspects of goal-directed executive control function (Bull et al., 2008; St. Clair-Thompson and Gathercole, 2006). Specifically, inhibition and working memory have both been implicated in mathematical and reading ability, while a lack of consensus exists regarding the role of cognitive flexibility on scholastic performance (Bull and Scerif, 2001; DeStefano and LeFevre, 2004; St. Clair-Thompson and Gathercole, 2006). St. Clair-Thompson and Gathercole (2006) used exploratory factor analysis to study the relationship between executive control and academic achievement (i.e., English, mathematics, and science) in 11–12 year old children, and identified two separate executive control factors, one associated with the updating of the contents of working memory and the other associated with the inhibition of unrelated information. The third executive control factor (i.e., cognitive flexibility) was not identified as having

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a distinct relationship with academic achievement. Such findings suggest that the executive control functions of working memory and inhibition are related to learning in the academic environment, and are consonant with other reports of the role of executive control in academic achievement, including those who demonstrate difficulties in academic subject matter (de Jong, 1998; Passolunghi and Siegel, 2001).

To date, these interesting linkages between academic achievement and executive control functions have been explored solely via task performance or in-class systematic observation (Mahar et al., 2006; Grieco et al., 2009), and have never been investigated using neuroelectric measurement. The study of the neuroelectric system provides a more direct means by which to examine underlying cognitive operations that occur between stimulus engagement and response execution. In particular, a class of the electroencephalogram, known as event-related brain potentials (ERPs), provides online measurement of cognitive processing; thus, potentially shedding light on specific aspects of cognition that constitute variability in scholastic performance. The P3 (i.e., P3b, P300) is a large positive-going peak of an ERP, which occurs approximately 300–800 ms following stimulus onset with maximum amplitude over the parietal cortex (Donchin et al., 1986). This endogenous component is thought to reflect neuronal activity associated with the revision of the mental representation of the previous event (Donchin, 1981), such that P3 amplitude is determined by the allocation of attentional resources toward the updating of working memory (Donchin and Coles, 1988). P3 latency is generally considered as a measure of stimulus detection and evaluation time (Ilan and Polich, 1999; Magliero et al., 1984), which is often independent of response selection and behavioral action (Verleger, 1997). Because P3 is sensitive to a host of cognitive and biological determinants (see Polich and Kok, 1995 for review), it is an intriguing component of the neuroelectric system that may lend itself well to the study of individual differences.

In the current study, a Go/NoGo task was used to elicit an ERP, because prior research suggests that the NoGo-P3 provides a direct measure of inhibitory control; thus serving as a biological marker for aspects of cognitive and/or neural inhibitory control (Kamarajan et al., 2005). This task requires individuals to discern between two stimuli under separate instruction conditions. In the Go condition, individuals are presented with a train of stimuli and are instructed to respond only on the rare occasion when a target stimulus is presented. Such stimulus presentation probabilities require attentional vigilance to the task to accurately detect the infrequent Go stimulus in order to update the contents of the working memory representation of the stimulus environment, whereby a prominent P3 potential overlying the parietal region of the scalp is observed. In the NoGo condition, a similar train of stimuli are provided and individuals are instructed to respond to the majority of stimuli, suppressing their response on only the rare occasion. As such, the NoGo condition requires inhibition of the prepotent response, and elicits a P3 characterized by a fronto-central scalp distribution that is thought to index inhibitory control (Johnstone et al., 2007; Kamarajan et al., 2005; Smith et al., 2004).

In the experiment reported herein, we examined the association between preadolescent children's Go/NoGo P3 amplitude with their performance on arithmetic and reading comprehension achievement from the Wide Range Achievement Test – 3rd edition (WRAT3). We hypothesized that the P3 would serve as a biological marker for performance on the WRAT3, with larger amplitude reflecting better achievement test performance. We further expected that this relationship would emerge despite the inclusion of other measures (i.e., IQ) with established relationships to academic achievement, suggesting the uniqueness of P3 in the explanation of scholastic performance.

2. Method

2.1. Participants

One hundred five preadolescent children (42 female; mean age: 8.8 ± 0.6 years) from the east-central Illinois region were recruited to serve as participants. The racial composition was similar to that of the county with 45% Caucasian, 31% African American, 13% Asian, and 11% Bi-racial or other ethnicities. All participants provided written assent and their legal guardians provided written informed consent in accordance with the Institutional Review Board of the University of Illinois at Urbana-Champaign. Prior to testing, legal guardians' completed a health history and demographics questionnaire, reported that their child was free of neurological diseases, attentional disorders (as indexed by scores below the 80th percentile on the ADHD Rating Scale IV; DuPaul et al., 1998), individualized educational plans, or physical disabilities, and indicated normal or corrected to normal vision. Socioeconomic status (SES) was determined using a trichotomous index based on: participation in free or reduced-price lunch program at school, the highest level of education obtained by the mother and father, and number of parents who worked full-time (Birnbaum et al., 2002)[1]. Legal guardian's, in collaboration with their child, completed the Tanner Staging System (Tanner, 1962), indicating that the participant's pubertal status was at or below a score of 2 (i.e., prepubescent) on a 5-point scale. Additionally, children were administered the Kaufman Brief Intelligence Test (K-BIT; Kaufman and Kaufman, 1990) by a trained experimenter to assess intelligence quotient, as well as the Edinburgh Handedness Inventory (Oldfield, 1971) to determine hand dominance. Demographic data for all participants is provided in Table 1.

[1] Participants' socioeconomic status (SES) was classified into three levels (low, moderate, and high). Individuals were considered to be of low SES if any of the following criteria occurred: (1) they received free or reduced price lunch, (2) both parents had less than a high-school education, or (3) they lived in a single parent household and that parent had less than a high-school education. Participants were considered to be of high SES if one or both parents had a college education *and* were employed. All other participants were considered to be of moderate SES.

Table 1
Mean (SD) values for participant demographics.

Variable	All participants
N	105
Age (years)	8.8 (.6)
Tanner stage	1.6 (.5)
K-BIT composite (IQ)	108.3 (11.3)
Socioeconomic status (SES)	1.9 (.9)
Body mass index (kg/m^2)	19.6 (4.7)
WRAT3 reading achievement	110.0 (13.1)
WRAT3 spelling achievement	106.1 (14.5)
WRAT3 arithmetic achievement	101.3 (15.8)

2.2. Measures

2.2.1. Academic achievement assessment

Academic achievement was assessed individually in the content areas of reading (i.e., the number of words correctly pronounced aloud), spelling (i.e., the number of words correctly spelled), and arithmetic (i.e., the number of mathematical computations correctly completed) using the Wide Range Achievement Test – 3rd edition (WRAT3; Wide Range, Inc., Wilmington, DE). The WRAT3 is a paper and pencil based academic achievement assessment that has been age-normed referenced and has been strongly correlated with the California Achievement Test – Form E and the Stanford Achievement Test (Wilkinson, 1993).

2.2.2. Neurocognitive assessment

Neuroelectric and behavioral indices of performance (i.e., reaction time, response accuracy) were collected in response to a Go/NoGo task (see Table 2). In the Go task, participants were instructed to respond with a right hand thumb press only when they saw an infrequent target stimulus (i.e., a cartoon drawing of a lion) and to ignore the frequent non-target stimulus (i.e., a cartoon drawing of a tiger). In the NoGo task, which was presented following the Go task, instructions reversed the response mappings of the target and non-target stimuli, such that participants were required to respond to the frequent stimulus (i.e., a cartoon drawing of a tiger) and inhibit the pre-potent response to the infrequent stimulus (i.e., a cartoon drawing of a lion). This manipulation allows for the elicitation of a P3 in response to the infrequent stimulus for both tasks, with the amplitude of the P3 being related to working memory demands in response to the Go task target condition (Polich, 2007) and inhibitory control demands in response to the NoGo task non-target condition (Johnstone et al., 2007; Kamarajan et al., 2005; Smith et al., 2004). In each task, participants completed two blocks of 125 trials, with the lion and tiger stimuli presented with a probability of .2 and .8, respectively. Stimuli appeared for 200 ms on a black background, with a 1700 ms inter-trial interval. Prior to beginning each task, participants completed a block of 40 practice trials.

Table 2
Task performance for the Go/NoGo task.

Measure	Response accuracy (% correct)	RT (ms)
Go target	91.7 ± 9.2	521.9 ± 77.9
Go nontarget	97.9 ± 2.3	–
Nogo target	79.6 ± 14.9	419.9 ± 71.7
Nogo nontarget	71.2 ± 14.3	–

Note: Mean ± SD.

2.2.3. ERP recording

Electroencephalographic (EEG) activity was recorded from 64 electrode sites (FPz, Fz, FCz, Cz, CPz, Pz, POz, Oz, FP1/2, F7/5/3/1/2/4/6/8, FT7/8, FC3/1/2/4, T7/8, C5/3/1/2/4/6, M1/2, TP7/8, CB1/2, P7/5/3/1/2/4/6/8, PO7/5/3/4/6/8, O1/2) arranged in an extended montage based on the International 10-10 system (Chatrian et al., 1985) using a Neuroscan Quik-cap (Compumedics, Inc, Charlotte, NC). Recordings were referenced to averaged mastoids (M1, M2), with AFz serving as the ground electrode, and impedance less than 10 kΩ. 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, amplified 500 times with a DC to 70 Hz filter, and a 60 Hz notch filter using a Neuroscan Synamps 2 amplifier. Continuous data were corrected offline for EOG artifacts using a spatial filter (Compumedics Inc., Neuroscan, 2003). Stimulus-locked epochs were created for correct trials 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 at 30 Hz (24 dB/octave). Trials with artifact exceeding ±75 μV were rejected. The P3 component was evaluated as the largest positive going peak within a 350–600 ms latency window, respectively. Amplitude was measured as the difference between the pre-stimulus baseline and maximum peak amplitude; peak latency was defined as the time point corresponding to the maximum amplitude. Given that the topographic maxima of the P3 to the Go task target condition and the NoGo task non-target condition varied between the central and parietal regions across participants, P3 amplitude and latency was calculated within each participant and task as the mean value across 9 electrode sites in a centro-parietal hot-spot (C1, Cz, C2, CP1, CPz, CP2, P1, Pz, P2). On average, 31.6 ± 6.8 trials were included in the Go task analyses and 27.9 ± 6.3 trials were included in the NoGo task analyses.

2.3. Procedure

2.3.1. Day 1

Academic achievement assessment. On the first visit to the laboratory, participants completed an informed assent, Edinburgh Handedness Inventory (Oldfield, 1971), as well as the Kaufman Brief Intelligence Test (K-BIT; Kaufman and Kaufman, 1990). Concurrently, participants' legal guardians completed an informed consent, health history and demographics questionnaire, the ADHD Rating Scale IV (DuPaul et al., 1998), and a modified Tanner Staging System questionnaire. Participants were then administered the Wide Range Achievement Test – 3rd edition (Wide Range, Inc., Wilmington, DE).

2.3.2. Day 2

Neurocognitive assessment. On the second visit (M days from day 1 = 11.8 ± 8.8), participants were fitted with a 64-channel Quik-cap (Compumedics Neuroscan Inc., El Paso, TX) and seated in a sound attenuated room where the neuroelectric testing took place. Following the provision of task instructions, participants were afforded the opportunity to ask questions and forty practice trials were administered prior to the start of testing. Upon completion of the last task condition, all electrodes were removed and participants were briefed on the purpose of the experiment.

3. Results

3.1. Data analysis

Bivariate correlation analyses were conducted using Pearson product-moment correlation coefficients between the three domains of academic achievement and the descriptive variables (e.g., age, sex, BMI, etc.), the behavioral variables (i.e., RT and accuracy) and ERP variables (i.e., amplitude and latency). Hierarchical linear regression analyses were then performed to explain variance in the domains of academic achievement. This was undertaken by regressing domains of academic achievement on statistically significant descriptive correlates (e.g., IQ) in Step 1 and statistically significant behavioral and ERP variables in Step 2. The significance of the change in the *R*-square value between the two Steps was used to judge the independent contribution of behavioral and ERP variables for explaining variance in academic achievement beyond that of the descriptive variables. This analysis was performed separately for each of the three domains of academic achievement. A conservative *p*-value of .01 was adopted along with a one-tailed test for judging statistical significance in all analyses given the number of tests in the bivariate and regression analyses. The data analysis was performed in PASW Statistics, 18.0.

3.2. Bivariate correlations

The correlations between descriptive variables and domains of academic achievement are provided in Table 3. K-BIT scores and SES were significantly associated with reading ($r = .40$ and $r = .30$, respectively), spelling ($r = .36$ and $r = .30$, respectively), and arithmetic ($r = .49$ and $r = .31$, respectively) performance. Grade was significantly associated with reading ($r = .29$) and spelling ($r = .25$), but not arithmetic ($r = .16$), performance. The other correlations for age, sex, BMI, Tanner stage, and race were not statistically significant.

The correlations between behavioral and ERP variables and domains of academic achievement are provided in Table 3. P3 amplitude to the Go task target condition was significantly associated with reading ($r = .27$), but not arithmetic ($r = .18$) and spelling ($r = .16$), achievement. P3 amplitude to the NoGo non-target task was significantly associated with reading ($r = .24$) and arithmetic ($r = .23$), but not spelling ($r = .16$), achievement. Lastly, the accuracy of performance for the NoGo task nontarget condition was significantly associated with arithmetic ($r = .31$), but not reading ($r = .15$) and spelling ($r = .20$), achievement. There were no significant correlations between either reaction time or P3 latency with academic achievement.

Table 3
Bivariate correlations between academic domains and demographic, behavioral, and neuroelectric variables.

Variable	Academic domain		
	Reading	Spelling	Arithmetic
Age (years)	.14	.03	−.09
Sex (0 = female, 1 = male)	.00	−.12	−.11
Body mass index (kg/m^2)	−.06	−.03	−.15
Tanner stage	−.04	−.01	−.11
Grade	.29*	.25*	.16
Socioeconomic status (SES)	.30*	.30*	.31*
Race (0 = white, 1 = nonwhite)	−.03	.11	.04
K-BIT composite (IQ)	.40*	.36*	.49*
Go task target condition RT	−.01	−.00	.15
NoGo task non-target condition RT	.00	−.16	−.19
Go task target condition response accuracy	.09	.12	.12
NoGo task non-target condition response accuracy	.15	.20	.31*
Go task target condition P3 amplitude	.27*	.16	.18
NoGo task nontarget condition P3 amplitude	.24*	.16	.23*
Go task target condition P3 latency	−.07	.04	−.08
NoGo task non-target condition P3 latency	−.14	−.08	.04

* $p < .01$ with one-tailed test.

Finally, Pearson product-moment correlation analyses were conducted on P3 amplitude and latency with task performance measures of RT and response accuracy because of the importance of this relationship for stimulus evaluation and inhibitory control. Response accuracy was associated with P3 amplitude ($r = .20$) and P3 latency ($r = -.22$) during infrequent trials in the NoGo task. Go target RT was negatively correlated with Go P3 amplitude ($r = -.20$). No other significant correlations were observed.

3.3. Regression analysis

Fig. 1 illustrates grand average waveforms and topographic plots for the Go and NoGo tasks. Fig. 2 illustrates the topographic distribution of partial correlations between P3 amplitude and academic achievement controlling for related descriptive variables.

3.3.1. Reading achievement

The results for the first regression analysis are in Table 4. The hierarchical regression analysis indicated that Grade ($B = 4.67$, SE $B = 1.85$, $\beta = .23$) and K-BIT ($B = 0.36$, SE $B = 0.12$, $\beta = .31$) explained a statistically significant ($F = 9.56$, $p = .001$) amount of variance in reading achievement ($R^2 = .22$) in Step 1. Only P3 amplitude to the Go task target condition explained a statistically significant ($F = 5.52$, $p = .005$) and incremental amount of variance in reading achievement beyond the variables in Step 1 ($\Delta R^2 = .08$) in Step 2. The scatter plot for the bivariate correlation between P3 amplitude to the Go task target condition with reading performance is in Fig. 3.

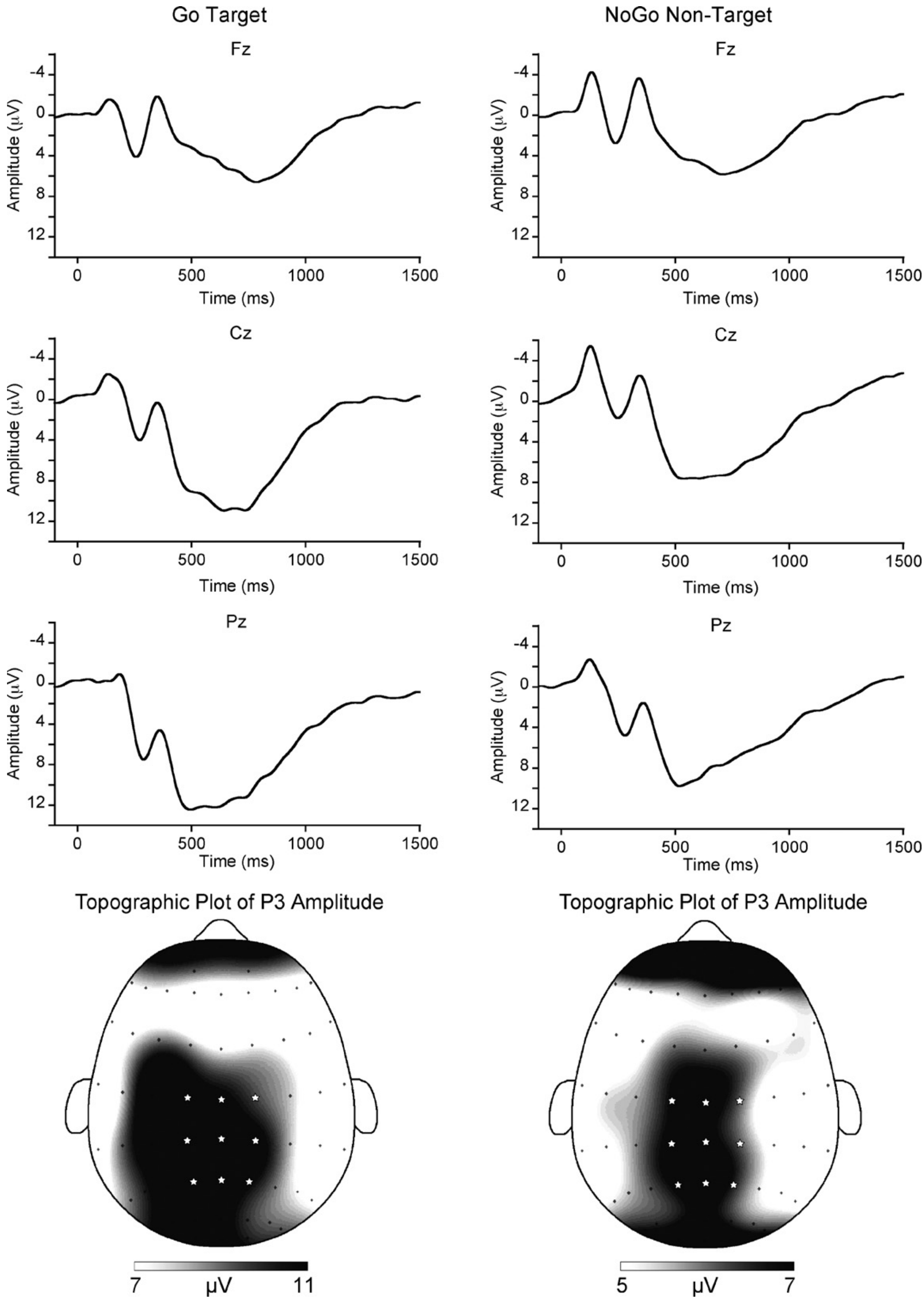

Fig. 1. Grand averaged ERP waveforms and topographic plots of the P3 component to the Go and NoGo tasks. Note that the nine electrode sites used in the analyses are depicted by white stars in the topographic plots.

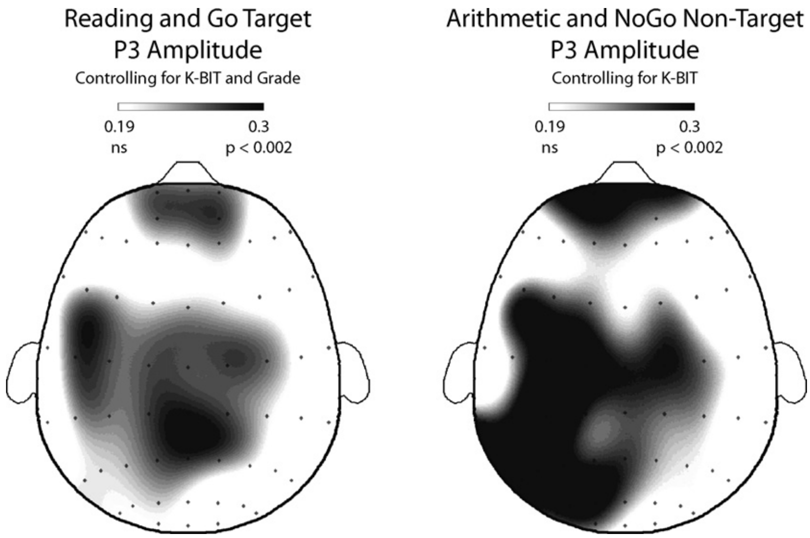

Fig. 2. Topographic plots illustrating the partial correlations between P3 amplitude in response to the Go task target condition and Reading achievement controlling for K-BIT and Grade (left) and P3 amplitude in response to the NoGo task non-target condition and Arithmetic achievement controlling for K-BIT (right) as a function of scalp topography.

Table 4
Summary of hierarchical regression analysis for reading achievement.

Variable	*B*	SE *B*	*β*
Step 1			
Grade	4.67	1.85	.23*
Socioeconomic status (SES)	1.49	1.45	.11
K-BIT composite (IQ)	0.36	0.12	.31*
Step 2			
Grade	4.63	1.78	.23*
Socioeconomic status (SES)	1.59	1.42	.11
K-BIT composite (IQ)	0.35	0.12	.30*
Go task target condition P3 amplitude	0.31	0.15	.21*
NoGo task nontarget condition P3 amplitude	0.18	0.18	.10

Note: R^2 = .22 for Step 1; ΔR^2 = .08 for Step 2 ($p < .05$).
* $p < .05$ with two-tailed test.

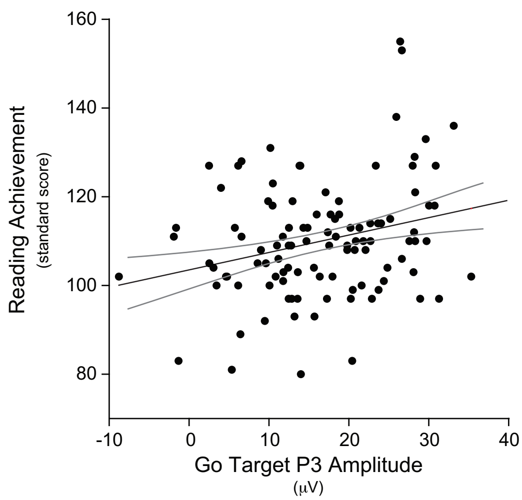

Fig. 3. Scatter plot with line of best fit and 95% confidence intervals for the bivariate associations between P3 amplitude for the Go task target condition with Reading achievement.

3.3.2. Spelling achievement

We did not undertake regression analysis for spelling achievement as there were no behavioral or ERP variables that correlated with this domain of academic achievement in the bivariate analysis.

3.3.3. Arithmetic achievement

The results for the second regression analysis are in Table 5. The hierarchical regression analysis indicated that K-BIT (B = 0.62, SE B = 0.14, β = .44) explained a statistically significant (F = 16.58, p = .001) amount of variance in arithmetic achievement (R^2 = .25) in Step 1. Both response accuracy (B = 0.29, SE B = 0.09, β = .27) and P3 amplitude to the NoGo task non-target condition (B = 0.52, SE B = 0.16, β = .26) explained a statistically significant (F = 10.36, p = .001) and incremental amount of variance in arithmetic achievement beyond the variables in Step 1 (ΔR^2 = .13) in Step 2. The scatter plots for the bivariate correlations between accuracy and P3 amplitude to the NoGo task non-target condition with arithmetic achievement are in Fig. 4.

Table 5
Summary of hierarchical regression analysis for arithmetic achievement.

Variable	*B*	SE *B*	*β*
Step 1			
Socioeconomic status (SES)	1.68	1.70	.10
K-BIT composite (IQ)	0.62	0.14	.44*
Step 2			
Socioeconomic status (SES)	0.70	1.58	.04
K-BIT composite (IQ)	0.63	0.13	.45*
NoGo task non-target condition response accuracy	0.29	0.09	.27*
NoGo task non-target condition P3 amplitude	0.52	0.16	.26*

Note: R^2 = .25 for Step 1; ΔR^2 = .13 for Step 2 ($p < .05$).
* $p < .05$ with two-tailed test.

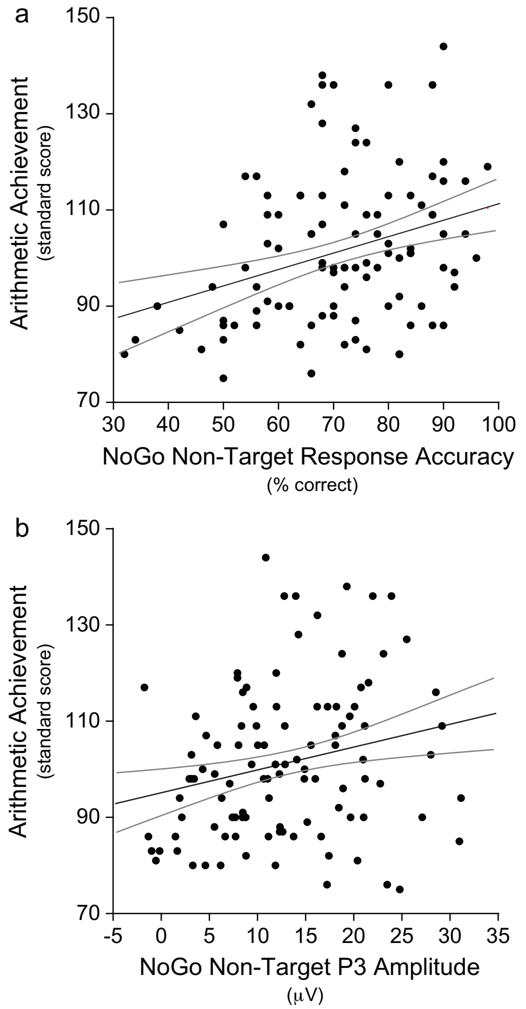

Fig. 4. Scatter plot with line of best fit and 95% confidence intervals for the bivariate associations between accuracy (a) and P3 amplitude (b) for the NoGo task non-target condition with Arithmetic achievement.

4. Discussion

The purpose of the present study was to provide early evidence to suggest that neuroelectric indices of attention and inhibition may serve as a biomarker of academic achievement in preadolescent children. Indeed, the results indicated that P3 amplitude accounted for unique variance in reading and arithmetic performance on the WRAT3, beyond the variance explained by IQ and task performance. Interestingly, the P3 component collected during two cognitive tasks (i.e., Go/NoGo), each tapping different aspects of cognition, displayed a differential relationship with reading and mathematics achievement, indicating the uniqueness of this potential in reflecting the underlying executive control requirements of each academic subject.

Specifically, P3 amplitude during the Go target condition exhibited a significant relationship only with reading achievement. Theories surrounding P3 to a Go task (i.e., also known as the oddball task) suggest that it reflects neuronal activity associated with revision of the mental representation of the previous event within the stimulus environment (Donchin, 1981). P3 amplitude is determined by the allocation of attentional resources when working memory is updated (Donchin and Coles, 1988), such that P3 is sensitive to the amount of attentional resources allocated to a stimulus, with larger amplitude reflecting greater amounts of attention (Polich, 1987; Polich and Heine, 1996). Accordingly, the data reported herein suggest that the P3 represents a neuroelectric index of attention allocation in the service of updating during reading comprehension, with larger amplitude (i.e., greater allocation of attentional resources) reflecting better updating capability, which in turn might relate to superior reading achievement.

Relative to arithmetic achievement, a relationship was observed for inhibition, with increased achievement related to better performance on the NoGo non-target condition. Beyond the relationship with NoGo task performance, NoGo-P3 amplitude exhibited a significant relationship with arithmetic achievement. Empirical evidence for NoGo-P3 indexing the control of inhibition exists (Kamarajan et al., 2005), providing support for a neuroelectric marker reflecting the inhibitory requirements underlying superior mathematics achievement. This assertion is consonant with other research suggesting that neural inhibition underlies the P3, with its amplitude reflecting the suppression of extraneous neuronal activity (Polich, 2007). As such, the current findings suggest that neuroelectric measures of inhibitory control contribute to the variance explained in mathematics achievement beyond that of task performance indices of inhibition.

To date, only one other report has described a relationship between academic achievement and aspects of the neuroelectric system. Hirsh and Inzlicht (2009) observed individual differences in error-related negativity (ERN) component amplitude to a Stroop color-naming task and scholastic performance of college-age students, as measured via grade point average. They reported that larger ERN amplitude following errors was related to better academic performance, and suggested that greater amplitude of this component reflected an increased ability to monitor performance and activate executive control mechanisms in support of scholastic performance (Hirsh and Inzlicht, 2009).

Although there were an insufficient number of errors of commission to reliably assess the ERN component in response to the tasks used within the current investigation, the present findings further extend the literature demonstrating unique relationships between working memory and inhibitory aspects of executive control with reading and mathematics achievement. Specifically, the current findings are consonant with those of St. Clair-Thompson and Gathercole (2006), who identified relationships between working memory and inhibition with academic achievement. Such a pattern of results was replicated herein with task performance measures of executive control, and extended to include neuroelectric indices supporting these aspects of cognition. These data also support the relationship between intelligence and academic achievement (Jensen, 1998), but indicate that intelligence does not fully explain scholastic success, as both task performance and neuroelectric variables continued to increase the amount of variance accounting for academic achievement.

In contrast, task performance measures of the Go/NoGo task largely did not relate to academic achievement. That is, only NoGo nontarget accuracy was related to arithmetic achievement, while RT across both conditions was unrelated to academic achievement. Thus, although response accuracy during task conditions requiring inhibition may index achievement in mathematics, such a finding might also suggest that the P3 component is a more sensitive marker of the various aspects of cognition underlying academic achievement. Alternatively, the demands of the Go/NoGo task are such that behavioral measures simply may not reflect the relationship between inhibition and working memory with academic achievement. That is, due to the relative ease of this task, little variance existed in Go task performance. However, task performance was relatively low in the NoGo task, with non-target response accuracy being the only measures associated with arithmetic achievement. Thus, it is possible that a lack of variance in certain task conditions may have prohibited such a relationship from being observed. Clearly, further research is necessary to determine the relationship between behavioral measures of inhibition and working memory with academic achievement.

It is important to note that these findings may not simply reflect a model in which working memory solely relates to reading achievement and inhibition solely relates to mathematics achievement. In fact, there is a wealth of literature demonstrating that inhibition relates to reading and working memory relates to mathematics (Bull and Scerif, 2001; Gernsbacher, 1993; St. Clair-Thompson and Gathercole, 2006). For instance, inhibition is necessary to suppress the automatic activation of inappropriate or irrelevant information for successful comprehension during reading (Gernsbacher, 1993) and problem solving during mathematics (Passolunghi and Siegel, 2001). Further, relevant information must be held in the contents of working memory for efficient and effective comprehension and problem solving during these aspects of achievement (Bull and Scerif, 2001; St. Clair-Thompson and Gathercole, 2006). As such, it is highly probably that the findings reported herein do not reflect a selective relationship between specific cognitive processes and specific academic skills. Rather, the data likely indicate that the P3 derived from specific cognitive tasks reflect components of achievement that are differentially reflected in these relationships. Some evidence exists to demonstrate that visuo-spatial working memory, relative to inhibition, accounts for a larger portion of the variance when explaining the relationship between cognitive control and English achievement (St. Clair-Thompson and Gathercole, 2006). In support of this relationship, the current data observed that the P3 derived from a task requiring visuo-spatial attention and working memory was related to reading achievement. As such, future efforts should be directed toward determining whether the P3 derived during other cognitive tasks may reflect these same areas of achievement (i.e., a global relationship) and thus may also serve as a general biomarker for scholastic success, or whether the relationships observed herein are selective to the cognitive and academic achievement tests. Through such research, we may not only be able to unpack aspects of scholastic achievement but we may also be able to determine which underlying processes account for the observed variance in scholastic success (i.e., working memory, inhibition, attention, long term memory, relational memory, etc.).

Finally, it is interesting to note that no relationship was observed for the P3 component and spelling achievement. Such a pattern of results indicates that the P3 may be an indicator of performance for select academic subject matter, rather than a general index of overall scholastic performance. However, the fact that the P3 from two different tasks (i.e., Go and NoGo) reflecting differential cognitive functions was observed suggests that this neuroelectric component might provide a novel approach to assessing specific aspects of academic achievement in children. Overall, the findings support the relationship of working memory and inhibitory aspects of executive control with academic performance, and suggest that P3 might represent a unique biomarker of achievement. Given that the child participants in this study were cognitively healthy and without individual education plans, such a measure may have important implications for educational practice, as it may assist in the identification of subclinical cognitive deficits, and allow educators to tailor their individual lesson plans to enhance learning.

Author disclosure statement

The authors declare no competing or conflicting interests.

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