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Improving kindergarten readiness in children with developmental disabilities: Changes in neural correlates of response monitoring

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Abstract

Among children diagnosed with developmental delays, difficulties in self-regulation are prominent and have been linked to school readiness problems. The current study sought to examine the impact of the Kids in Transition to School (KITS) school readiness intervention program on self-regulation, with a specific focus on response monitoring skills, among children with developmental delays. Children (*n* = 20 in the KITS group and *n* = 21 in a services as usual group) were administered a flanker task during which event-related potential data were collected to examine group differences in response monitoring. Findings indicated that children in the KITS group showed significant enhancement of a neural index of response monitoring post-intervention. Specifically, the KITS group showed a significant change in the magnitude of their feedback-related negativity in response to negative performance feedback from baseline to post-intervention, whereas children in the services as usual group did not. There were no significant differences between the groups for the error-related negativity or the error-related positivity on incorrect trials nor were there group differences in behavioral performance on the task at the post-intervention assessment. Overall, these findings provide support for the plasticity of response monitoring skills in young children and support the growing literature demonstrating improved self-regulation outcomes via intervention that enhances children's response monitoring.

Keywords

ERP; feedback; intervention; preschool; response monitoring; self-regulation

Introduction

Children entering formal schooling for the first time are likely to face a new set of rules and activities for which they will have varying degrees of preparation. An important support skill

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for school readiness is children's ability to distinguish whether they are performing a new skill or task well. This performance monitoring, or response monitoring, involves children's ability to recognize feedback from others about whether they have made a mistake, as well as their ability to recognize internally when they have made a mistake; in turn, these abilities allow for corrective action and adjustment of behavior in accordance with task demands (for a review, see McDermott & Fox, 2010). Children who are "*tuned in*" to their performance are able to seek out relevant information in learning new skills, recognize pertinent feedback about when they are not doing well, and—eventually—recognize for themselves when they are performing the skill well. Conversely, children who are not able to utilize this information may quickly face academic and social difficulties. Thus, the ability to effectively monitor one's own successful (or unsuccessful) performance may be a foundational skill that helps prepare children for the academic and self-regulation challenges experienced in the school setting (McDermott, Westerlund, Zeanah, Nelson, & Fox, 2012).

Neural markers of response monitoring

As noted above, children who are not able to recognize when they have made mistakes may have difficulties not only in the academic domain, as they fail to understand when they are not performing tasks well, but also in the social domain, perhaps repeating actions that peers and adults find irritating. Response monitoring has been shown to be compromised during cognitive and attentional tasks in children with academic and social difficulties, such as children with attention-deficit/hyperactivity disorder and autism spectrum disorder (e.g., Vlamings, Jonkman, Hoeksma, van Engeland, & Kemner, 2008; Wiersema, van der Meere, & Roeyers, 2005). Deficits in response monitoring could have a number of underlying causes. For example, children who have been told that they have not done a task correctly multiple times, yet persist in making the same mistakes, may have underlying problems with feedback processing or motivation. Looking beyond global measures of behavior to the electrophysiological markers of response monitoring has the potential to provide greater specification of underlying causes of deficits in school readiness skills. This could lead to the creation of more efficacious and perhaps more cost-effective interventions.

At a neural level, responses to mistakes and performance feedback have been investigated with event-related potential (ERP) data. An ERP is a transient voltage fluctuation generated by large populations of localized neurons that is time locked to a discrete event, such as the participant's behavioral response to a task (i.e., a button press). ERP data have excellent temporal resolution (in milliseconds) and provide information about the sequence of cognitive processes. Assessing electrophysiological markers of response monitoring might be especially important because prior research findings suggest that measures of behavior and brain activity can provide divergent information (Bruce, McDermott, Fisher, & Fox, 2009; Karayanidis et al., 2000)—that is, despite the absence of a group difference on behavioral performance, patterns of brain activity significantly differ between groups. This pattern of results is believed to represent a subtle difference in cognitive processing that behavioral measures cannot detect (Karayanidis et al., 2000). In addition, behavioral performance reflects the final output resulting from the confluence of multiple cognitive processes; thus, it is difficult to attribute behavioral performance to a specific cognitive process (Luck, 2005). In contrast to behavioral data, the temporal resolution of ERP data allows researchers to isolate the brain activity related to specific cognitive processes, such as response monitoring.

Three primary ERP components have been linked to response monitoring: the error-related negativity (ERN), the error-related positivity (Pe), and the feedback-related negativity (FRN). The ERN is a negative deflection typically peaking 100 ms after the participant's response (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993), and the Pe is a positive deflection peaking 100–500 ms after the participant's response (Overbeek, Nieuwenhuis, & Ridderinkhof, 2005). The FRN is a negative deflection typically peaking 200–500 ms after the presentation of performance feedback (Bruce et al., 2009; Gehring & Willoughby, 2002; Moser & Simons, 2009). The ERN and the Pe are believed to reflect internal response monitoring because they occur immediately after a response. Therefore, they are indications that an individual has processed, either consciously or unconsciously, that he or she made a mistake. In contrast, the FRN is time locked to experimenter-generated performance feedback indicating the accuracy of an individual's response and thus is believed to reflect an individual's reaction to external evaluative information.

Although there are large individual differences in ERP responses, and thus no cutoffs to indicate typical amplitudes for a particular ERP component, the ERN, the Pe, and the FRN have consistently been more pronounced in response to *errors or negative performance feedback* across individuals. Specifically, the ERN should be more negative in amplitude and the Pe should be more positive in amplitude when an individual makes a mistake. The FRN would be expected to be more negative in amplitude to feedback indicating that an individual's response was incorrect. The enhanced amplitudes of these components following inaccurate performance reflects the notion that information about mistakes is expected to be more salient than information about correct answers when tasks have clear response contingencies. Moreover, feedback indicating a mistake garners more attention and heightened neural processing, because it should signal to the individual that he or she needs to change behaviors or strategies.

All three ERP components have been linked to the anterior cingulate cortex (see Gehring, Liu, Orr, & Carp, 2012), a neural region involved in multiple cognitive processes that contribute to self-regulation (Bush, Luu, & Posner, 2000; Shenhav, Botvinick, & Cohen, 2013). Recent studies also implicate the anterior insula in the Pe response (Schroder, Moran, Moser, & Altmann, 2012; Ullsperger, Harsay, Wessel, & Ridderinkhof, 2010). Developmental work suggests that the ERN and the Pe increase in magnitude with age, suggesting that neural regions underlying internal response monitoring continue to mature into adolescence (Torpey, Hajcak, Kim, Kujawa, & Klein, 2012; Tamnes, Walhovd, Torstveit, Sells, & Fjell, 2013). In contrast, current work indicates a clear presence of the FRN in older children (Crowley et al., 2014; Groen et al., 2008) and preschoolers (Bruce et al., 2009; Mai et al., 2011; Roos, Pears, Bruce, Kim, & Fisher, 2015).

Risk for response monitoring deficits in children with developmental delays

Assessing neural markers of response monitoring may be particularly important for populations of children who have difficulties with self-regulation and subsequent school adjustment, such as children with developmental delays. This group often exhibits particular problems in self-regulation (Reed, McIntyre, Dusek, & Quintero, 2011) that might cause cascading difficulties in their academic performance and social relationships (Eisenhower, Baker, & Blacher, 2007; Kemp & Carter, 2000). Conversely, better self-regulation can serve as a protective factor for these children with higher emotion regulation linked to better social adjustment (Baker, Fenning, Crnic, Baker, & Blacher, 2007; Wilson, 1999).

Research on specific self-regulation skills, such as response monitoring, among children with developmental delays is limited (Pears, Kim, Healey, Yoerger, & Fisher, 2015), and work on neural markers of response monitoring among this population has focused largely on adults, older children, or specific disabilities. One of the few studies of children with developmental disabilities—in this case Specific Language Impairment—revealed diminished responding to errors across the three primary response monitoring ERP components (i.e., the ERN, the Pe, and the FRN; Arbel & Donchin, 2014). Studies have also shown that children with autism spectrum disorder tend to exhibit poor response monitoring on cognitive and attentional tasks (Vlamings et al., 2008). To date, no work has examined these components among preschool aged children with a heterogeneous range of developmental disabilities—the typical population of children moving from preschool special education services into kindergarten.

Intervention effects on neural markers of response monitoring

Understanding the effects of behavioral interventions on the neural underpinnings of self-regulation could be very beneficial for our understanding of how interventions change children's trajectories for several reasons. First, neural changes in response monitoring may appear prior to changes in behaviors. Reliance solely on behavioral indicators could obscure a full understanding of an intervention's effects. Second, behaviors are multiply determined. A behavioral change does not necessarily provide information about the precise effects of an intervention. For example, increased accuracy in a behavioral response to a stimulus may indicate an increase in motor skills, decision making skills, or response monitoring skills. By examining ERP components that are linked to specific cognitive processes, it is possible to more precisely pinpoint an intervention's effects. Finally, there have recently been concerns about the "fadeout" of intervention effects over time. It is possible that the effects of interventions that change neural response patterns are more sustained over time. Thus, measuring intervention effects on neural responses could be critical to understanding the specific mechanisms through which interventions have their effects and how to better sustain those effects.

Elucidating the effects of interventions on key neural mechanisms, such as the neural markers of response monitoring, may be particularly important for children at high risk for difficulties in school, such as children with developmental disabilities. As noted previously, deficits in self-regulation appear to play a large part in those difficulties and determining the specific aspects of self-regulation being affected by behavioral interventions is critical to ensuring the efficacy of interventions. Moreover, tracking whether changes are taking place at a neural level may also provide valuable information about the potential stability of the effects of interventions over time.

Current study

The present study examined the effects of the Kids in Transition to School (KITS) intervention on the neural correlates of response monitoring in children who had received preschool services for developmental disabilities or delays and who had co-occurring behavioral difficulties. The KITS program was designed to promote self-regulatory, as well as social and early literacy, skills in children who are entering kindergarten and are at high risk for poor school adjustment. A key feature of the intervention is the provision of consistent, contingent feedback about children's performance while they learn and develop a variety of school readiness skills. Such feedback is designed to increase children's abilities to regulate their own behaviors. Children were tested on a computer-administered flanker task during which feedback performance was provided after each trial. We hypothesized that children who received the KITS intervention would show improved behavioral accuracy on the task during the period from the pre-intervention baseline at the beginning of the summer to the end of the summer before kindergarten entry compared to children who received services as usual. Furthermore, we predicted that children who had received the intervention would show changes in the ERP components indexing internal response monitoring with the intervention leading to enhanced neural processing of mistakes as evidenced by more negative ERN and more positive Pe amplitudes on incorrect trials over time. Similarly, we expected children in the intervention to display increased responding to external performance feedback as exhibited by more negative FRN amplitudes to negative feedback over time. This pattern would signify that children were becoming more attentive to the salient information about mistakes, thus making it more likely that they could subsequently change their behavior.

Methods

Participants

The 41 children in this study were a subsample of a larger sample (N = 209) selected for the randomized controlled trial of an intervention to promote school readiness in children with developmental disabilities and delays who also had behavior problems that might interfere with their transition to kindergarten. The entire sample was recruited in cohorts of 50 children per year across 4 years. Because of funding restrictions, it was not possible to collect ERP data from all of the children in the sample; only the last two cohorts had the opportunity to complete this assessment. However, all of the eligibility requirements and recruitment procedures were identical for all four study cohorts (described in the following section). For a consort diagram of the entire sample, please refer to Pears, Kim, Fisher, and Yoerger (2016).

Children were referred for participation in the study through the local public agency responsible for Early Childhood Special Education (ECSE) services in a medium metropolitan area of the Pacific Northwest. To be eligible for the study, the child had to be transitioning to kindergarten, have a developmental disability or delay as identified by the agency providing services, and have behavioral difficulties as determined using the Early Screening Project Questionnaire (Walker, Severson, & Feil, 1995) described below. A child was ineligible for the study if he or she had hearing or vision impairments that would limit participation, had an IQ below 70, was not a monolingual or bilingual English speaker, was in a foster care placement (to avoid overlap with a separate randomized controlled trial of KITS with children in foster care), or was receiving full-time ECSE services in the summer. For every child who had received ECSE services through the agency and was entering kindergarten in the fall, the service providers rated the child's level of social and behavioral problems using a questionnaire from the Early Screening Project (Walker et al., 1995). Children could receive a final behavioral risk score from 0–4 denoting the number of scales on which they had scored within the critical range. A project staff member contacted parents of children who scored one and above and met all of the other eligibility criteria to set up a home visit to explain the project and obtain informed consent. Children and families were then randomized using computer software that randomly assigned children to groups while balancing those groups by gender and final behavioral risk score. There were no significant differences on demographic factors (child gender, age, ethnicity, disability diagnosis, and behavioral difficulties score) between the families who were randomized to a group and those families who chose not to respond or participate.

The final two cohorts of children participated in assessments to collect ERP data at the beginning of the summer before kindergarten prior to the start of the intervention (Time 1 [T1]) and at the end of the summer just prior to the start of school (Time 2 [T2]) of the year that they were starting kindergarten. Eighty-four families completed the assessment at either T1 or T2, and 67 families completed the assessment at both time points. To be included in analyses, the children had to complete assessments that resulted in 10 or more trials with useable ERP data per trial type (i.e., correct vs. incorrect trials) for each component of interest (i.e., ERN, Pe, and FRN) at T1 and T2. Forty-one children met these criteria, 20 of whom were from the KITS group and 21 of whom were from the services as usual (SAU) group. The characteristics of these children are presented in Table 1 by group. These 41 children did not differ from the children who did not complete the ERP assessments on age, child gender, ethnicity, final behavioral risk score, or disability category, nor did they differ from one another by intervention group on these variables.

Intervention protocol

The KITS intervention consisted of two primary components: a 24-session school readiness group and an 8-session parent group (both described in greater detail below). The total duration of the full intervention protocol was 4 months. The school readiness phase (approximately two thirds of the curriculum) occurred in the 2 months before kindergarten entry and focused on preparing the children and parents for school, and the transition/ maintenance phase occurred during the first 2 months of kindergarten and focused on supporting a positive transition to school. The current study focused on the school readiness phase of the intervention to be able to examine the most immediate effects of the intervention before those effects might be moderated by effects of the kindergarten classroom environment or curriculum after school entry.

The *school readiness group* sessions occurred two times a week for 2 hours during the 2 months of the summer school readiness phase (16 sessions) and one time a week for 2 hours during the 2 months of the transition/maintenance phase (8 sessions). The 24 total sessions were designed to be similar to a kindergarten classroom with a highly structured, consistent routine, and many transitions between activities. The manualized school readiness group curriculum covered: *self-regulatory skills* (e.g., handling frustration and disappointment, controlling impulses, following multistep directions, listening, and making appropriate transitions), *prosocial skills* (e.g., reciprocal social interaction, social problem solving, and emotion recognition), and *early literacy skills* (e.g., letter names, phonological awareness, print conventions, and comprehension). Given the links between self-regulatory skills and response monitoring, that aspect of the curriculum is highlighted here.

Self-regulatory skills were taught using a blend of instruction (e.g., teachers talk specifically about the importance of handling frustration), role-playing (e.g., teachers model specific techniques for handling frustration and children practice), and activity-based intervention (e.g., children play games requiring that they wait for their turn and handle the disappointment of being called “out” of a game). The children received clear feedback and guided practice in using the target skills. They were provided with clear, specific information about what they had done well and step-by-step feedback on how to improve skills that still needed development. A graduate-level lead teacher and two assistant teachers conducted the school readiness groups with 12–15 children. The high staff-to-child ratio provided children with high levels of support and feedback while practicing new skills. The same lead teacher and assistant teachers delivered the entire intervention.

The parent group meetings occurred once every 2 weeks for the entire 4 months of the intervention for 2 hours at a time (12 sessions). The times coincided with the school readiness group meeting times. Each group was led by a facilitator and an assistant. The manualized parent curriculum included *foci* on promoting child self-regulation (e.g., behavior management skills that parallel those used in the school readiness groups). The facilitator presented information, led structured group discussions of the materials, and addressed questions and concerns. Skill acquisition was reinforced via role plays and discussion. Any parent who had missed a meeting received a home visit (or a phone call if necessary) from the facilitator to cover the content and materials for that session.

Services as usual (SAU) group

Children in this group received services in the community that are typically offered to children with developmental disabilities and delays, including ECSE services and evaluation, individual and family therapy, and participation in early childhood education and care programs. Types and amounts of services varied for each individual. No attempt was made to influence the type or amount of services. The most accessed services for both the SAU and the KITS groups with the percentages of each group that used them were special education services (SAU = 42%; KITS = 36%), parks and recreational programs (SAU = 30%; KITS = 31%), individual therapy (SAU = 8%; KITS = 6%), case management services (SAU = 6%; KITS = 3%), family therapy (SAU = 5%; KITS = 10%), and psychological assessment (SAU = 5%; KITS = 5%). Frequency of usage of services ranged from one time in the two months of the summer to more than one time a week in both groups. There were no differences between the SAU and KITS groups on the percentage of children who received any given service or the frequency with which they used the services.

Data collection procedures

At T1 (before the start of the intervention) and T2 (at the end of the school readiness phase of the intervention and before the start of school), the families participated in center-based assessments. There were a mean number of 83 days (SD = 18 days) between the two assessment points for the KITS group and a mean number of 79 days (SD = 19 days) for the SAU group. This time frame was not significantly different between the two groups ($t(df)$ = −0.86, p = .40). All data collection staff members were blind to the group assignment of the children and parents, and all study procedures were approved by the Institutional Review Board at the Oregon Social Learning Center.

Measures

Flanker task—Behavioral and ERP data were recorded during a colored circles version of the flanker task (McDermott, Perez-Edgar, & Fox, 2007) that was presented with the STIM Stimulus Presentation System, James Long Company (Caroga Lake, NY). Children were instructed to respond to the middle circle in a row of five colored circles. The task was comprised of congruent and incongruent trials. Congruent trials consisted of a row of either all green or all red circles, whereas incongruent trials consisted of either a central green circle surrounded by red circles or a central red circle surrounded by green circles. Congruent and incongruent trials were presented in a random order at a 70:30 ratio (incongruent trials: congruent trials). Before beginning the task, children were asked to identify the colored circles to verify visual accuracy and color familiarity, and they were also tested on task terminology to verify comprehension of task instructions. Eight practice trials were completed prior to the test trials. Children were instructed to respond as quickly and accurately as possible.

Trials began with a warning cue that was shown for 300 ms followed by a fixation mark for 500 ms presentation. Next, the stimulus (row of circles) was presented for 700 ms with a total response window of 1300 ms. Following a response or trial timeout, a 450 ms fixation screen appeared, followed by performance feedback (in the form of a 1-inch smiling or frowning schematic face) presented for 800 ms. Children completed three test blocks of 60 trials each (180 trials total). Total test time was approximately 20 minutes.

EEG recording and reduction—Electroencephalogram (EEG) was recorded in accordance with the International 10–20 system (Jasper, 1958). The International 10–20 system is an internationally recognized method to describe the location of EEG scalp electrodes. Each site has a letter code to identify the lobe of the brain and a number code to identify the hemisphere location. The letters F, T, C, P, and O stand for frontal, temporal, central, parietal, and occipital lobes, respectively. (There is no central lobe; the C is used only for identification purposes.) Even numbers refer to electrode positions on the right hemisphere, whereas odd numbers refer to those on the left hemisphere. Z (zero) refers to an electrode placed on the midline. Channels were referenced to Cz (central midline) with Afz (anterior frontal midline) serving as ground. All impedances were at or below 10 kΩ. Vertical electrooculogram was collected by two mini electrodes with one placed directly above and one directly below the left eye.

Electrophysiological signals were amplified via SA Instrumentation Bioamps with filter settings of 0.1 to 100 Hz. Data were digitized at 512 Hz by a DATAQ Instruments A/D converter. For ERP analysis, a 30-Hz low-pass filter was applied, eye movement was regressed, and data exceeding +/− 200 microvolts were excluded. Data were processed with an average mastoids configuration. ERP epochs were created with a 100 ms baseline occurring prior to the participant response or feedback presentation. Children with excessive noise in the EEG data or less than 10 usable trials per trial type per time point were excluded. Among the children included in the final analyses, there was an average of 80 (SD = 35.58) and 32 (SD = 10.73) trials for correct and incorrect response-locked ERPs, respectively, and 81 (SD = 34.95) and 31 (SD = 10.55) trials for correct and incorrect feedback-locked ERPs, respectively. The SAU and KITS groups did not differ in the number of usable trials (all t values for paired t-tests were less than or equal to −1.46, and all p values for the paired t-test were greater or equal to 0.15). Peak amplitude was assessed on the following ERP components of interest: the ERN and the Pe that were time-locked to the participant response and the FRN that was time-locked to presentation of performance feedback. Consistent with prior work on these ERP components in children (Roos et al., 2015; Santesso et al., 2008), visual inspection of the grand means for the response-locked components (ERN and Pe) confirmed that these components were present in the sites of Fz (frontal midline), Fcz (frontal central midline), and Cz; whereas, the feedback-locked component (FRN) was most pronounced at sites Fz and Fcz. The ERN and Pe were examined in windows of — 50–100 and 50–300 ms after the response, respectively. For the Pe, a peak-to-peak difference score was calculated to account for any preceding differences in the ERN. The FRN was examined in a window of 200–500 ms after the feedback and calculated as a peak-to-peak difference score accounting for the preceding P2 component (scored in the window of 100–300 ms after the feedback).

Statistical procedures

To examine group differences (KITS vs. SAU) in changes in response monitoring over time (T1 vs. T2), a series of repeated-measures analyses of variance (RM-ANOVAs) were used in SPSS.

Behavioral accuracy—A RM-ANOVA was run to investigate group differences in behavioral accuracy over time on the congruent and incongruent trials. In this RM-ANOVA, group (KITS vs. SAU) was entered as a between-subjects factor and trial type (congruent vs. incongruent) and time (T1 vs. T2) were entered as within-subjects factors.

Neural reactivity—To assess neural reactivity, separate RM-ANOVAs were run for each ERP component of interest (i.e., ERN, Pe, and FRN) to examine change across time for correct and incorrect trials separately. For each RM-ANOVA, group (KITS vs. SAU) was entered as a between-subjects factor with electrode site (ERN and Pe: Fz, Fcz, vs. Cz; FRN: Fz vs. Fcz) and time (T1 vs. T2) entered as within-subjects factors. Across all analyses, Greenhouse-Geisser corrections for sphericity were applied (and epsilons [ε] are reported) when appropriate (Greenhouse & Geisser, 1959). Partial eta-squared $\left(\eta_p^2\right)$ was used to measure effects sizes because it is an indication of the amount of variance in the outcome explained by the predictor. It has been recommended that values of .0099, .0588, and .1379 be interpreted as small, medium, and large effects, respectively (Cohen, 1969; Richardson, 2011). Key interaction findings were followed up with appropriate independent and paired-samples *t*-tests to determine the precise associations among the variables. For all analyses, a *p* value of 0.05 or lower was taken to indicate statistical significance, whereas a *p* value greater than 0.05 but less than 0.07 was considered to indicate a statistical trend.

Results

Behavioral data

The RM-ANOVA to examine change in percent of correct trials indicated a main effect of time (see Table 2) such that children performed more accurately at T2 ($M = 62.36$, $SD = 14.28$) compared to T1 ($M = 56.58$, $SD = 14.92$). Additionally, the children performed better on the congruent ($M = 62.86$, $SD = 14.59$) than the incongruent trials ($M = 58.01$, $SD = 13.12$) indicating the expected flanker effect on the task. There was neither a significant main effect of group nor a significant interaction of time x group. The means for each group by time and type of trial are presented in Table 3.

Neural reactivity data

ERN—The main effects for electrode site, time, and group were not significant for correct trials. Furthermore, no significant interactions emerged. For all of the RM-ANOVAs to measure neural reactivity, the F values, epsilons for the Greenhouse-Geisser corrections, and effect sizes are shown in Table 4. The grand average waveforms to incorrect responses at each electrode site are pictured in Figure 1.

For incorrect trials, the main effect of electrode site was significant. Post hoc paired samples *t*-tests showed that the ERN at each site was significantly different than that at each of the other sites. The *t* values ranged from 2.27 to 2.92 with *p* values from 0.03 to 0.01. The most negative ERN was at Fz ($M = -0.64$ µV, $SD = 6.03$ µV), followed by Fcz ($M = 0.41$ µV, $SD = 6.37$ µV), and then Cz ($M = 1.28$ µV, $SD = 6.50$ µV). The main effect for time showed a trend toward significance with a more negative ERN at T2 ($M = -0.76$ µV, $SD = 7.45$ µV) compared to T1 ($M = 1.46$ µV, $SD = 6.55$ µV). Neither the main effect for group nor any of the interactions were significant.

Pe—For correct trials, a main effect of electrode site emerged. Post hoc paired samples *t*-tests showed the Pe was more prominent at Fz ($M = 8.06$ µV, $SD = 6.51$ µV) and Fcz ($M = 7.19$ µV, $SD = 5.28$ µV) compared to Cz ($M = 6.02$ µV, $SD = 4.59$ µV). The *t* values were 2.69 and 2.60, respectively, with a *p* value of .01 for both. The magnitude of the Pe at Fz was slightly greater than Fcz at trend level ($t(40) = 1.91$, $p = 0.06$). There was not a main effect of time and none of the interactions were significant. A main effect of group emerged. Specifically, the SAU group exhibited a larger Pe to correct responses ($M = 8.74$ µV, $SD = 5.75$ µV) than the KITS group ($M = 5.36$ µV, $SD = 3.71$ µV).

For the incorrect trials, there were no significant main or interaction effects.

FRN—There were no main effects for electrode site or time for the FRN in response to positive feedback A main effect for group emerged with the KITS group displaying an overall larger FRN to positive feedback (M = −16.21 μV, SD = 4.82 μV) compared to the SAU group M = −12.87 μV, SD = 5.03 μV). Additionally, there were no significant interaction effects.

In response to negative feedback, no main effects for electrode site, time or group were found for the FRN. However, a significant time x group interaction emerged as illustrated in Figure 2a, b. Post hoc paired samples t-tests revealed a significant difference between T1 and T2 for the KITS group (t(19) = 3.20, p = .005), such that this group exhibited a larger FRN in response to negative feedback at T2 (M = −20.78 μV, SD = 8.94 μV) compared to T1 (M = −15.57 μV, SD = 6.51 μV). In contrast, there was no significant difference for the SAU group between T1 and T2. Additionally, an independent samples t-test (t(39) = 2.63, p = .012) confirmed that the magnitude of change in the FRN between T1 and T2 was significantly different between groups (see Figure 3) with the KITS group exhibiting an increased FRN (i.e., more negative) over time (M = −5.21 μV, SD = 7.30 μV) compared to the SAU group who showed a reduced (i.e., less negative) FRN to over time (M = 2.12 μV, SD = 10.22 μV).

Discussion

In an era of diminishing funding for school programs, the ability to provide time-limited, focused programs to enhance self-regulation and subsequent school adjustment may become increasingly important. In this study, we have shown that a relatively short-term, theoretically-based intervention can alter the neural processing of children with developmental disabilities and delays and co-occurring behavior problems. Specifically, children who had received an intervention to promote school readiness, with a particular focus on enhancing self-regulation, showed improved response monitoring over time as indicated by a more negative FRN in response to feedback that they had made an error. This pattern suggests an increased prioritization of cues relevant to one’s own performance. Enhanced response monitoring is theorized to be an essential component to school readiness and to strongly influence children’s ability to function adaptively in school, an environment in which they are frequently being asked to learn and perform new skills. Moreover, the pattern of reduced neural processing of relevant feedback cues over time in the children who did not receive the intervention is consistent with prior work demonstrating reduced skills for at-risk children who do not receive interventions over the summer period (Alexander, Entwisle, & Olson, 2001). Taken together, these results underscore the need for more extensive scaffolding in at-risk populations of children throughout the year.

Overall, these results add to a budding literature demonstrating that behavioral interventions can alter children’s neural processing. Several studies of foster care intervention programs have demonstrated associations between interventions and changes in neural indices of response monitoring (Bruce et al., 2009; McDermott et al., 2012; McDermott et al., 2013). The current study presents similar findings, using pre- to post-intervention data, provoking the question: what elements do these interventions have in common that might contribute to changes in neural processing? A common element of all of the interventions is the goal of promoting structure in the children’s environments. For example, in a study of maltreated children in foster care (Bruce et al., 2009), the intervention entailed placing children with foster caregivers who had been trained to create structured, consistent environments and provide clear and explicit feedback for the children. Similarly, a foster care intervention for children who had been institutionalized promoted stable relationships between the caregivers and children and greater consistency in caregiving (Nelson et al., 2007; Smyke, Zeanah, Fox, Nelson, & Guthrie, 2010). In the current study, the school readiness intervention featured a classroom and behavior management model with an emphasis on providing children with clear and contingent feedback within the context of learning new skills. Additionally, the intervention included meetings in which parents learned to provide clear and consistent feedback as part of positive parenting skills. Recent research has shown that, over time, the parents in the KITS intervention showed decreases in their inconsistent parenting (Pears et al., 2015). Collectively, these findings suggest that interventions that emphasize the provision of clear, contingent, consistent feedback—and a consistent environment—may improve children's response monitoring skills. Additionally, they suggest that these intervention elements may be important to children from a variety of backgrounds, including children who have experienced considerable early adversity and those who have experienced developmental disabilities and delays.

Although intervention effects were found on the FRN in the current study, there were no corresponding intervention effects on the ERN and Pe. In fact, the ERN during incorrect trials was not clearly delineated in this sample at T1 and showed a modest, yet significant, increase in magnitude at T2. Although some evidence suggests that the ERN is smaller in magnitude among children than adolescence and adults, the lack of a clear ERN response at the first assessment suggests that this component may be further attenuated among children with developmental disabilities. Future work should examine the potential for prolonged intervention effects across early childhood on the ERN among this population.

In contrast to the ERN, the PE was more clearly pronounced in this sample. This pattern corresponds to work showing that the Pe emerges at younger ages than the ERN (Davies, Segalowitz, & Gavin, 2004) and underscores the uniqueness of these components in indexing error processing. However, a surprising group effect emerged for the Pe on correct trials, such that the SAU children exhibited a larger Pe to accurate responses—suggesting heightened focus on positive performance outcomes across time. One possibility is that the Pe on correct trials may reflect a stronger uncertainty in performance in this group (despite similar levels of accuracy and reaction) that manifests as stronger orientation to accurate performance. Although prior research postulates that detecting correct performance is distinct from detecting errors, little work has begun to unpack the precise function and neural substrates of correct trial processing in very young children, and future longitudinal work is needed to address the function of the Pe across early childhood.

The most prominent ERP component, the FRN, exhibited the most direct impact of the intervention, as children in the KITS group showed an increase over time in their neural reactivity to feedback indicating errors. This shift may reflect strengthening awareness of relevant cues that inform appropriate adjustment of behavior. It also suggests plasticity in this response monitoring skill that may be particularly useful for improving self-regulation among this population. Indeed, the clear presence of the FRN in this sample may reflect the earliest emerging aspect of response monitoring developmentally (Eppinger, Mock, & Kray, 2009; Hämmerer, Li, Müller, & Lindenberger, 2011), as children may initially be reliant on external feedback when learning which responses are correct and which responses are incorrect. As feedback becomes internalized, children may begin to show a more pronounced ERN to incorrect responses. Moreover, it is important to note that task difficulty is a key factor in the ability to internalize feedback. The flanker task used in the current study is often challenging for young children, thus promoting the need for children to rely on external feedback during the task. Last, it is important to note that children in the KITS group also showed a strong response to feedback indicating correct performance. This finding was similar to the pattern of enhanced processing of the Pe on correct trials for the SAU group. Thus, collectively, stronger neural reactivity to correct performance may be an underlying commonality to children with developmental disabilities that deserves further investigation.

Overall, the current study suggests that the ability to process and rely on concrete feedback information regarding performance accuracy (i.e., FRN) is modifiable in among young children with developmental disabilities and delays; whereas, improvements in more abstract levels of performance monitoring (i.e., ERN and Pe) may take longer to emerge developmentally and/or require lengthier experience with the intervention to produce substantial change. Contrary to hypotheses, there were no intervention effects on the children's behavioral performance over time. Other researchers have also found significant group differences on electrophysiological performance while failing to find significant differences on behavioral performance (Burgio-Murphy et al., 2007; Harter, Lourdes, Wood, & Schroeder, 1988; Karayanidis et al., 2000). Some have suggested that this pattern may reflect greater sensitivity of the ERP data to performance deficits (Harter et al., 1988) or alternate processing strategies that nonetheless result in similar behavior (Karayanidis et al., 2000). In view of the overall poor behavioral performance in the current study, the children may have to learn to differentiate between feedback indicating correct and incorrect responses before they can change their behavior. This may support the former theory with the ERP data indexing more sensitive neurological shifts that may precede later behavioral changes (Astle & Scerif, 2009).

Several limitations of the current study should be mentioned. First, the sample is relatively small. This is due in part to the practicalities of having young children with developmental disabilities and delays perform a task that is challenging for them. However, it is important to note that the children who were able to complete the assessment did not differ on a number of important characteristics from children who were not able to perform the task. Second, the sample was composed of children with developmental disabilities and delays, but the small sample size precluded examining performance by disability diagnosis. The presence of a variety of disabilities in the sample reflects the heterogeneous nature of the population of young children who receive early intervention and ECSE services (Scarborough, Hebbeler, Spiker, & Simeonsson, 2007). However, given that the majority of the children who participated in this ERP study were diagnosed with developmental or communication delays, the results might be most generalizable to those groups of children. Third, all of the children in the current study had been selected because they demonstrated behavioral difficulties that were likely to interfere with their transition to kindergarten. Thus, the results of this study may not be generalizable to the larger population of young children with developmental disabilities and delays. Future work should address whether the same kind of intervention effects on neural activity are found in groups of children with specific developmental disabilities and children with developmental disabilities but no co-occurring behavior problems. The children who participated in this study will be followed over time; thus, future work will also focus on whether intervention effects on response monitoring are related to better subsequent school functioning and whether effects persist over time. Another study with this sample documented that intervention effects on behavioral and emotional self-regulation persisted through the end of kindergarten, as reported by their teachers (Pears et al., 2015).

Despite these limitations, this study used a strong randomized controlled design with pre- and post-intervention assessment. The study demonstrated that an intervention to improve school readiness, with a particular emphasis on increasing children's abilities through the provision of clear and consistent feedback in the groups and by encouraging parents to utilize consistent behavior management strategies, could significantly impact children's response monitoring. Children's responses to salient performance feedback about incorrect response became more pronounced over time. This increased awareness could subsequently impact children's functioning as they transition to school, making them better able to distinguish the feedback that provides information about which skills and responses are incorrect and need to be improved. Thus, they may be better able to adjust their own behavior to the demands of the classroom and overall learning environment, although this will need to be tested in future studies. Overall, this type of intervention may help to ameliorate school adjustment and achievement for a very high-risk population.

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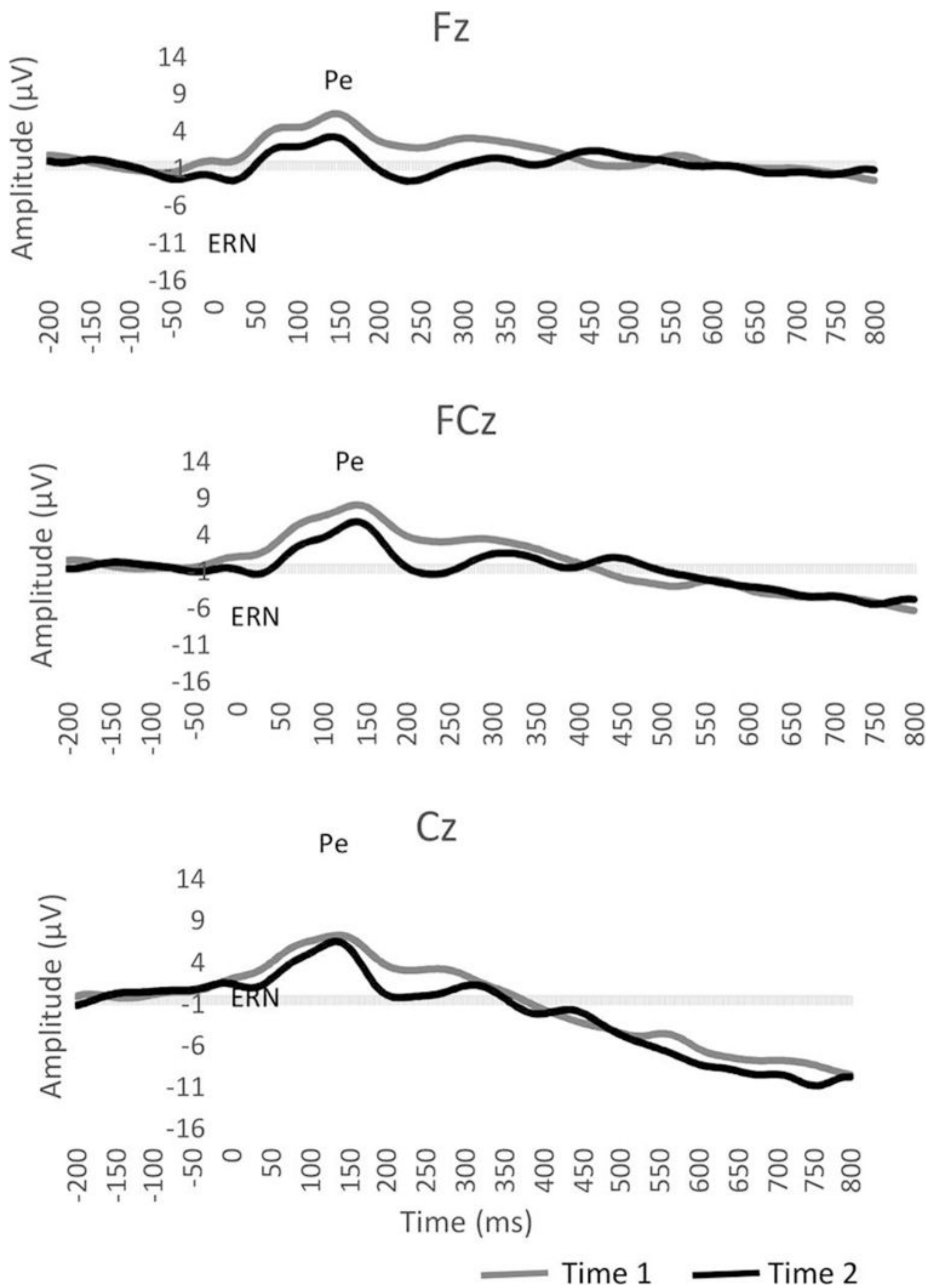

Figure 1.
Grand average ERP waveforms to incorrect responses for each electrode site.

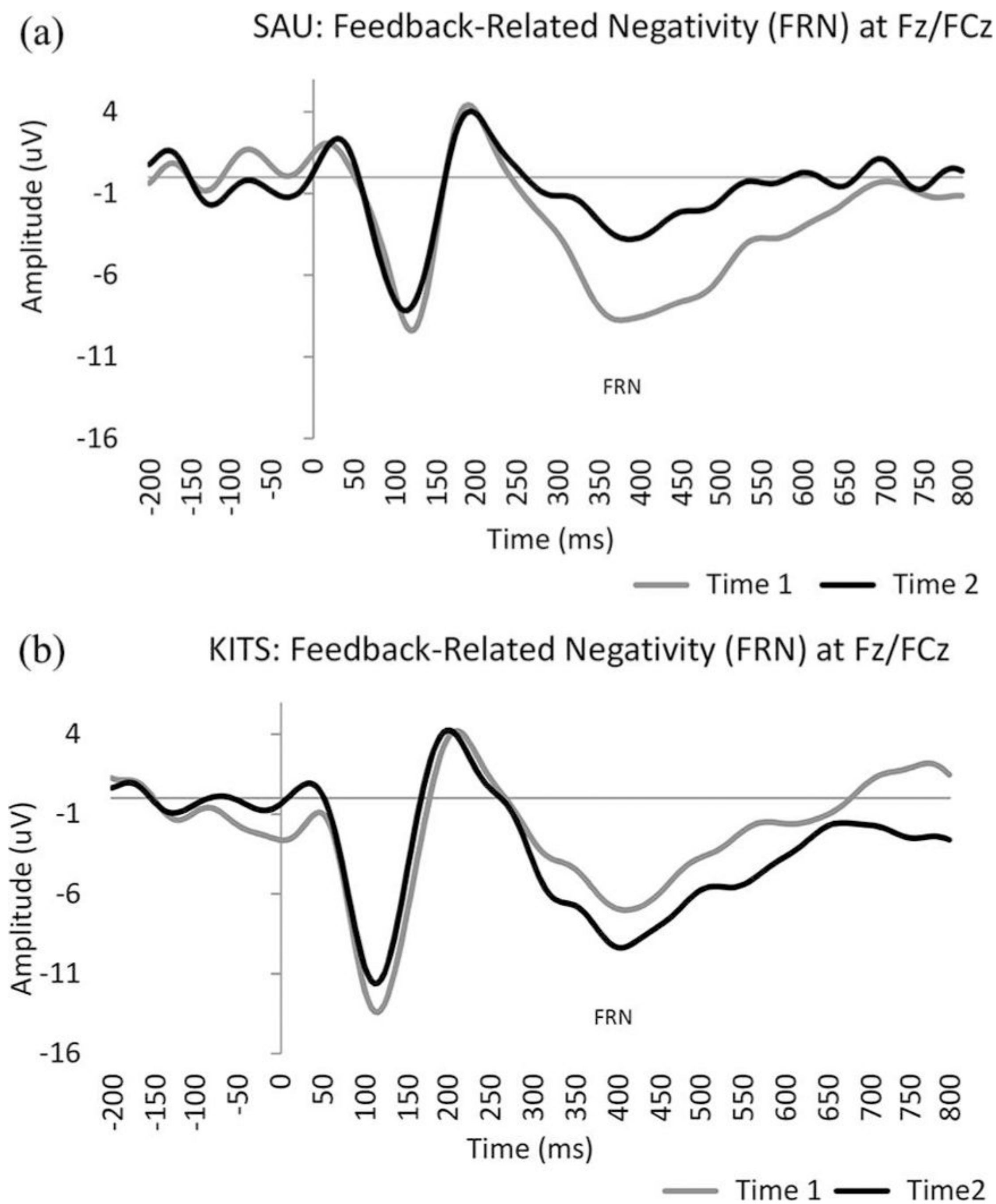

Figure 2.

(a and b) Grand average ERP waveforms to negative feedback at T1 and T2 by group.

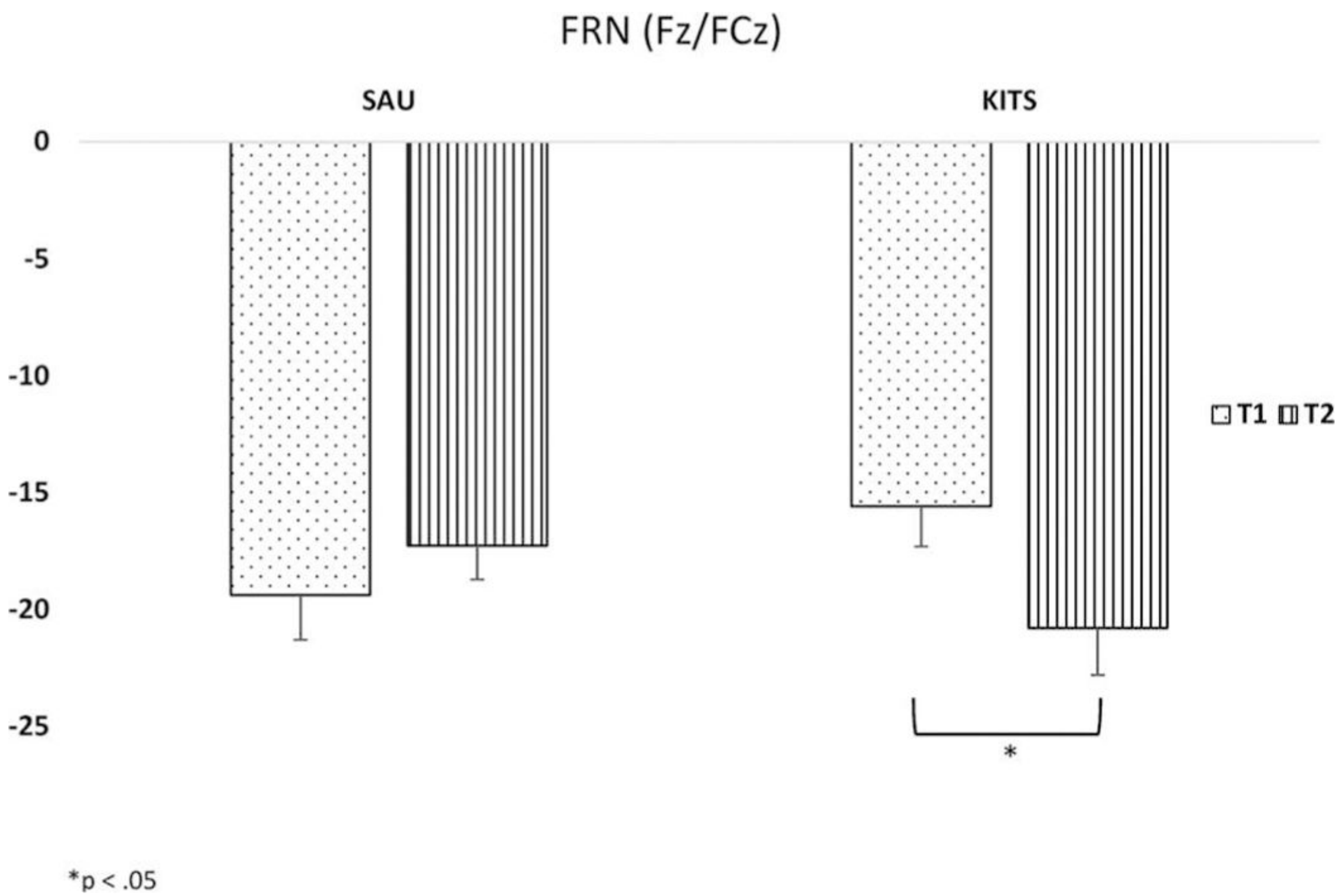

Figure 3.
Amplitude of FRN at T1 and T2 by group.

Table 1.

Baseline characteristics of the study sample by group.

	KITS Group (n = 20)	SAU Group (n = 21)	Comparison between KITS and SAU groups
Child mean age (SD) in years	5.26 (0.26)	5.24 (0.30)	$F = .03$, $p = 0.87$
Child gender (%)			$\chi^2 = 1.87$, $p = 0.17$
Male	85	67	
Ethnicity (%)			$\chi^2 = 4.30$, $p = 0.12$
European American	85	71	
Latino	15	10	
Mixed race	0	19	
Mean final behavioral risk score (SD)	2.45 (1.10)	2.05 (1.16)	$F = 1.30$, $p = 0.26$
Child disability category (%)			$\chi^2 = 0.74$, $p = 0.69$
Developmental delay[a]	65	52	
Communication delay[b]	30	43	
Autism	5	5	

Note.

[a]This category encompasses delays, as measured by the appropriate diagnostic instrument, in any of the following areas: physical development, cognitive development, communication development, social or emotional development, or adaptive development.

[b]The child evidences a delay that is specific to speech, language, or voice.

Table 2.

Repeated measures analyses of variance for behavioral accuracy on the Flanker task.

Source	***F***	η_p^2
% Correct		
Time	7.57*	0.16
Trial type	24.90*	0.39
Group	0.001	0.00
Time × Trial type	0.94	0.02
Time × Group	1.42	0.04
Trial type × Group	0.60	0.02
Time x Trial type × Group	1.65	0.04

Note. df for all analyses = 1, 39.

*$p < .05$.

Table 3.

Means for behavioral accuracy on the flanker task by trial type, group, and time.

	KITS group		SAU group	
	T1	T2	T1	T2
	M (SD)	M (SD)	M (SD)	M (SD)
	% Correct			
All trials	55.06 (13.16)	63.73 (12.71)	58.03 (16.62)	61.06 (15.84)
Congruent trials	60.28 (13.72)	66.34 (14.29)	60.71 (18.07)	64.11 (18.36)
Incongruent trials	52.82 (13.61)	62.61 (12.64)	56.88 (16.70)	59.75 (15.30)

Table 4.

Repeated measures analyses of variance for the electrophysiological measures.

Source	Correct trials *F*	Correct trials *ε*	Correct trials η_p^2	Incorrect trials *F*	Incorrect trials *ε*	Incorrect trials η_p^2
ERN						
Electrode site[a]	1.61	0.65	0.04	7.41[*]	0.64	0.16
Time[b]	2.09		0.05	3.83[+]		0.09
Group[b]	0.02		0.00	0.84		0.02
Electrode site × Time[a]	0.26	0.65	0.01	1.48	0.68	0.04
Electrode site × Group[a]	0.38	0.65	0.01	0.19	0.64	0.01
Time × Group[b]	1.14		0.03	.001		0.00
Electrode site × Time × Group[a]	0.70	0.65	0.02	0.18	0.68	0.01
Pe						
Electrode site[a]	6.41[*]	0.68	0.14	2.03	0.55	0.05
Time[b]	2.33		0.06	0.36		0.01
Group[b]	4.95[*]		0.11	0.41		0.01
Electrode site × Time[a]	0.51	0.69	0.01	0.38	0.63	0.01
Electrode site × Group[a]	2.31	0.68	0.06	0.19	0.55	0.01
Time × Group[b]	2.06		0.05	2.32		0.06
Electrode site × Time × Group[a]	0.37	0.69	0.01	2.50	0.63	0.06
FRN						
Electrode site[b]	3.03		0.07	0.80		0.02
Time[b]	0.83		0.02	1.23		0.03
Group[b]	4.70[*]		0.11	0.004		0.00
Electrode site × Time[b]	0.14		0.004	0.05		0.001
Electrode site × Group[b]	0.21		0.01	0.06		0.002
Time × Group[b]	2.13		0.05	6.93[*]		0.15
Electrode site × Time × Group[b]	0.05		0.001	1.26		0.31

[a] *Note*. *df* = 1, 31.

[b] *df* = 2, 31.

[c] *df* = 2, 62.

[d] *df* = 4, 62.

[+] p < .07.

*p < .05.