Published in final edited form as:

Brain Cogn. 2011 June ; 76(1): 77–86. doi:10.1016/j.bandc.2011.02.015.

How semantic categorization influences inhibitory processing in middle-childhood: An Event Related Potentials study

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Abstract

Throughout middle-childhood, inhibitory processes, which underlie many higher order cognitive tasks, are developing. Little is known about how inhibitory processes change as a task becomes conceptually more difficult during these important years. In adults, as Go/NoGo tasks become more difficult there is a systematic decrease in the P3NoGo response, indicating the use of effective inhibitory strategies (Maguire et al., 2009). This paper investigates the age at which children employ similar inhibitory strategies by studying behavioral and Event Related Potential (ERP) measures of response inhibition for three Go/NoGo tasks. Seventeen 7z8 year-olds and twenty 10–11-year-olds completed three Go/NoGo tasks that differed in the level of categorization necessary to respond. Both age groups displayed slower reaction times as the tasks became more difficult. Further, both groups displayed the predicted Go versus NoGo P3 amplitude differences in the two simplest tasks, but no significant P3 differences for the most complex task. The reason for this pattern of responses was different in the different age groups. Similar to adults in previous work, the oldest children showed an attenuation of the P3 NoGo response with task difficulty, and no corresponding changes in the Go amplitude. The younger children displayed the opposite pattern, a significant increase in the Go amplitude with task difficulty, and no changes in the NoGo response. These response patterns indicate that efficient inhibitory strategies are developing throughout middle-childhood.

Keywords

Response Inhibition; Middle Childhood; Event Related Potentials; Categorization

Middle childhood is a period of marked increases in inhibitory control (Brocki & Bohlin, 2004; Levin et al., 1991; Williams, Ponesse, Schachar, Logan, & Tannock, 1999), a broadly defined cognitive ability that provides a building block for many higher-level cognitive tasks (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Nigg, 2000; Williams et al., 1999). One difficulty in studying the development of this essential skill is that it does not occur in isolation, but instead operates on other cognitive processes, such as perception, motor response, categorization and language (Friedman & Miyake, 2004; Nigg, 2000; Shilling, Chetwynd, & Rabbitt, 2002). Surprisingly, despite our acknowledgment of the potential impact of these other variables on measures of inhibitory function, little work has uncovered

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how these influences are handled as inhibitory processes improve throughout middle childhood.

Amongst the most commonly documented manifestations of inhibitory processing are the Event Related Potentials (ERPs) associated with response inhibition in Go/NoGo tasks. In these tasks, participants press a button for one type of stimuli (Go) and withhold a button response for a second type of stimuli (NoGo). Successful response inhibition relates to the ability to stop oneself from responding during the NoGo trials. This provides a reliable index of response inhibition (Brocki & Bohlin, 2004; Johnstone, Pleffer, Barry, Clarke, & Smith, 2005; Levin et al., 1991) and elicits the P3 ERP response in adults and children (Bruin, Wijers, & van Staveren, 2001; Davis, Bruce, Snyder, & Nelson, 2003; Smith, Johnstone, & Barry, 2006, 2007, 2008).

Despite broad and important commonalities, many Go/NoGo studies report somewhat different electrophysiological and behavioral developmental patterns, such as differences in the age at which the P3 appears and when behavioral responses are adult-like in speed and accuracy (e.g., Ciesielski, Harris, & Cofer, 2004; Davis et al., 2003; Johnstone et al., 2005; Jonkman, 2006). Researchers widely acknowledge that these discrepancies are likely caused by design differences in the various Go/NoGo tasks (Cragg & Nation, 2008; Jonkman, 2006). Indeed, the range of Go/NoGo tasks is quite broad, from as simple as differentiating two tones (e.g., Johnstone et al., 2005; Ciesielski, Harris, & Cofer, 2004), to more complex, requiring categorization of letters or novel, abstract shapes (e.g., Brocki & Bohlin, 2004; Shue & Douglas, 1992). However, other than a handful of studies on the influence of the speed of presentation (Lindqvist & Thorell, 2009; Wiersema et al., 2006), little is known about how such variables influence measures of response inhibition, or how the ability to handle such variables changes with age. In this paper, we use ERPs to investigate how variations in one commonly found difference between response inhibition tasks, categorization, influence children's response inhibition processes in early (7–8 years) and later (10–11 years) middle-childhood.

It is essential to study the influence of categorization on response inhibition for a variety of reasons. First, one of the clearest, and most common, differences across Go/NoGo tasks is whether they require some form of categorization across items (e.g., Brocki & Bohlin, 2004; Davis et al., 2003; Shue & Douglas, 1992) or not (e.g., Ciesielski et al., 2004; Johnstone et al., 2005). Further, executive functions, like attention and inhibition, are rarely dependent on just one feature (Friedman & Miyake, 2004). Instead, in real world situations, whether to attend or ignore information depends on complex, abstract features. Thus, studying how abstract categorization influences response inhibition brings us a step closer to understanding real world inhibition situations.

Unlike previous studies that have investigated simple task variations like speed of presentation (Wiersema et al., 2006; Lindqvist & Thorell, 2009), categorization, and object categorization specifically, can tap into both basic level perceptual skills and higher level abstract-semantic skills depending on the level of categorization required (French, 1995; French, Mareschal, Mermillod, & Quinn, 2004; Goldstone & Barsalou, 1998; Murphy & Kaplan, 2000; Schyns, Goldstone, & Thibaut, 1998). Basic level categories, such as dogs or cows, are maximally perceptually similar within category and thus rely heavily on perceptual processes (French et al., 2004; Tanaka, Luu, Weisbrod & Kiefer, 1999). This is because basic level categories share many common physical features. As a result, basic level object categorization can occur using perceptual feature detection. The use of perceptual information in basic level categorization is most evident in the fact that even pre-lingual infants, as young as 3–4 months of age, group dogs as distinct from cats based on commonalities and differences in their component visual features (French et al., 2004). The

age at which this is possible for children rules out the reliance on language to form these categories. Many categories that are used daily by children and adults necessitate processing beyond perceptual similarities. An example would be the superordinate category food, which includes perceptually distinct items such as a sandwich and an apple. In such cases, there are no easily identifiable features that can be used to signal group membership. As a result, the additional information provided by language may be necessary to correctly identify items as members of this superordinate category. It is possible that perceptually based categorization may not significantly influence response inhibition abilities, even in young children. On the other hand, superordinate language-dependant categories that require abstract semantic categorization may interfere with the ability to perform simultaneous inhibitory functions. In fact, Tanaka, Luu, Weisbrod and Keifer (1999) found that identifying objects at the superordinate level (dog) resulted in a large frontal negative deflection in the ERP when compared to object identification at the basic level (dog) or subordinate level (beagle) which resulted in a larger N1 over posterior areas. They related these differences to differential recruitment of semantic and visual processing based on the level of object identification.

Although behaviorally, children reliably categorize at the superordinate level at relatively young ages (Mandler, Bauer, & McDonough, 1991; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), the speed and efficiency of this development appears to continue throughout middle childhood (Batty & Taylor, 2002). For example, in an ERP study, Batty and Taylor (2002) asked participants ages 7 years through adulthood to respond to pictures of animals and withhold their response for all other pictures. Even the youngest children (7–8 years old) had very high accuracy rates (96%), indicating that behaviorally this task was quite simple for them. Further, the P3 response differentiated animals from non-animals in all age groups. However, the latency of this effect was still decreasing until the age of 11. This indicates that while superordinate categorization is behaviorally adult-like around the age of 7, the efficiency of this core cognitive ability continues to develop into middle childhood. The fact that superordinate categorization is developing through middle childhood makes it an important variable to study in relation to response inhibition. Given the prolonged development of this ability, such abstract, superordinate categorization may display a significant influence on response inhibition, especially in children under the age of 11.

To date, most studies of neural correlates of object categorization focus only on abstract superordinate distinctions (Batty & Taylor, 2002; Kincses et al., 2006; Schumacher, Wirth, Perrig, Strik, & Koenig, 2009; Thorpe, Fize & Marlot, 1996; VanRullen & Thorpe, 2001). They rarely include multiple levels of abstraction to uncover how perceptual and semantic information may differentially influence this ability (but see Tanaka, Luu, Weisbrod, & Kiefer, 1999 for an exception). Further, they do not often investigate the influence of categorization on the inhibitory processes specifically. To our knowledge only one study has directly compared levels of categorization in an inhibition task (Maguire et al., 2009). In this study, adult participants each performed three Go/NoGo tasks at varying levels of abstraction. In each task, the Go items were presented 80% of the time and the NoGo items were presented 20% of the time. The “Single” task included the repetition of one image of a car (Go) and one image of a dog (NoGo). This could be performed at a perceptual level because identical images were repeated in a random order. The “Multiple” task contained multiple pictures of cars (Go) and multiple pictures of dogs (NoGo) that varied in orientation and subordinate type. Thus, correctly responding required identifying common perceptual features of the items, such as eyes and legs or tires and windshields, and then categorizing them based on their semantic level representation (dog or car). The “Semantic” task was the least perceptual, most conceptual-semantic task. It included a wide range of

perceptually dissimilar objects, such as a table, a lunch bag, and a car (Go) and a range of animals, such as an earthworm, a penguin, and a dog (NoGo).

Maguire et al (2009) found that within each of the three tasks the P3 inhibitory response was found, with larger amplitudes for NoGo compared to Go items. In comparing across tasks, the P3 NoGo response systematically decreased with the conceptual difficulty of the task, but the P3 Go response was not significantly influenced by complexity. If equal attention was given to the Go and NoGo items, the P3 Go responses would likely also be influenced by task difficulty. Thus, these results indicate that the adults strategy included searching for and attending to NoGo items, in particular, while to some degree filtering out the Go items. This strategy is quite efficient given that the NoGo items are significantly less common. Because both categorization and inhibition are improving between the ages of 7 and 11, it seems likely that these types of strategies are also developing throughout middle childhood and thus becoming more adult like. However, to date, little is known about this developmental change.

Both fMRI and ERPs have provided some evidence that children in middle childhood are not yet using adult-like mechanisms to perform response inhibition tasks (Durstun, Thomas, Yang, Ulug, Zimmerman, & Casey 2002; Davis et al., 2003; Liston, et al., 2006; Rubia et al., 2006; Velanova, Wheeler, & Luna, 2009). Durstun et al (2002) found that between the ages of 6 years and adulthood the ability to withhold a response to a NoGo trial increased with age, a behavioral difference that was also related to an increase in the use of the fronto-striatal circuitry. Further, when more Go trials preceded a NoGo trial, making inhibitory responses more difficult, adults displayed higher levels of activity within the inhibitory circuit. Children, on the other hand, did not show differences in activity based on the difficulty of the inhibitory response.

Potential behavioral strategies related to developmental differences in Go and NoGo responses between early middle childhood and adulthood were noted by Davis et al (2003). When completing a Go/NoGo task that required participants to press a button for all letters that were not X, and withhold a response for an X, Davis et al. found that 6-year-olds displayed large P3 NoGo and Go responses. This was compared to adults who displayed only a large NoGo response. The authors concluded that this may be because children deploy equal resources for both Go and NoGo trials, while adults attend preferentially to the NoGo trials. Thus, changes in the P3 response, and specifically those related to the NoGo response, may be an indicator of strategies employed to successfully perform a response inhibition task. By comparing across tasks that require varying degrees of abstract categorization, like the ones used by Maguire et al. (2009), we may be able to identify how children handle additional cognitive demands often related to response inhibition performance in middle childhood.

The goal of this paper is to study the influence of categorization on behavioral and ERP correlates of inhibitory function. In particular we are interested in the P3 ERP component. Traditionally, inhibitory function has been associated with two different ERP components, the N2 and the P3. The N2 is found over fronto-central areas, peaking around 250 ms after stimulus presentation. The P3 includes two components, referred to as the P3a and the P3b. The P3a has a fronto-central distribution and is most commonly observed in oddball paradigms when novel stimuli, unrelated to the task, are processed by the participant (Polich, 2003; Opitz, 2003). The P3b has a centro-parietal scalp distribution and is more closely related to inhibitory processes because it is measured in studies that evoke some type of evaluation of stimuli and require a response (Kok, 2001; Opitz, 2003). Although there is substantial debate concerning whether the N2 or the P3 is the stronger measure of response inhibition (Barry, Johnstone & Smith, 2003; Bruin, Wijers, & van Staveren, 2001; Kirmizi-

Alsan et al, 2006; Lavric, Pizzagalli, & Forstmeier, 2004; Smith, Johnstone, & Barry, 2006, 2007, 2008; Proverbio, Del Zotto, Crotti, & Zani, 2009); there is a general consensus that both are markers of inhibition to some degree (Smith et al., 2007). Previous work (Maguire et al., 2009) has shown that the P3 in particular, and not the N2, is influenced by the level of semantic processing associated necessary in a Go/NoGo task. The goal of the current study is to determine how that influence changes with development. As a result, the P3 will be the focus of this paper.

Developmentally, the P3 is expected to decrease in latency and increase in amplitude with age (Johnstone et al., 2005). More importantly, the relationship between Go and NoGo responses is expected to change with age and task difficulty. We hypothesize that younger children, similar to Davis et al. (2003), will display similarly sized P3 Go and NoGo responses across the tasks, and that task difficulty will influence the amplitude of both responses. This would indicate that younger children are allocating similar attentional resources to both types of stimuli. We predict that for the older children, each of these tasks, regardless of difficulty, will elicit the traditional P3 inhibition response: larger amplitudes for the NoGo items compared to Go items. Further, the older children will exhibit the influence of task difficulty only in the NoGo P3 response. This would indicate that the older children, like the adults in Maguire et al (2009), are exhibiting some ability to filter out the Go items and focus on the less common, NoGo items, during these tasks. Our developmental predictions are based on the fact that by age 10 or 11 children are responding in adult like ways during both categorization and inhibition tasks (Batty & Taylor, 2002; Brocki & Bohlin, 2004; Levin et al., 1991; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). Further, these differences would elucidate various strategies used in successful response inhibition in early and late middle-childhood.

Methods

Participants

Twenty-nine 7–8 year olds and twenty-five 10–11 year olds initially performed three Go/NoGo tasks. Subjects were not included in the final analysis if one or more tasks included major movement artifact, excess noise, or failure to comprehend the instructions. Further, after incorrectly responded to items and noisy EEG data were removed, the ERP data needed to include at least 30 useable trials across the three the NoGo conditions. These criteria excluded a total of 12 7–8 year olds and 5 10–11 year olds. This resulted in seventeen 7–8 year olds (5 females, 12 males) and twenty 10–11 year olds (12 females, 8 males) in the final analysis.

Subjects were screened, per exclusion criteria, to be native-English speakers, free from history of traumatic brain injury and other significant neurological issues (CVA, seizure disorders, history of high fevers, tumors, or learning disabilities). Exclusion criteria also included left-handedness and medications other than over-the-counter analgesics. Informed written ascent was collect from each child and consent was collected from each subjects parent according to the rules of the Institutional Review Board of The University of Texas at Dallas.

Stimuli

The stimuli were similar to those used in Maguire, et al (2009) and each followed the basic Go/NoGo paradigm. In each task, there were 160 (80%) Go stimuli, for which the subject was to press a button and 40 (20%) NoGo stimuli, for which the subject was instructed to withhold a response. In each of the three tasks, stimuli were presented for 300 milliseconds

followed by a fixation point (+) for 1700 milliseconds. All of the stimuli were black line drawings fitted to a white 600×600 pixel square.

As can be seen in Figure 1, in the Single task, the Go stimulus was a drawing of a car and the NoGo stimulus was a line drawing of a dog. In the Multiple task, the Go stimuli included 40 cars and the NoGo stimuli included 10 dogs, which were each repeated 4 times each. Each participant saw each of the cars and the dogs presented in a random order. To facilitate the use of perceptual cues in the Multiple task all dogs and cars were presented in profile. This allowed the participant to view the features that would be most beneficial in identifying and differentiating the dogs (e.g., nose, legs, tail) and the cars (e.g., windshield, car body, wheels). In the Semantic task, the Go stimuli consisted of 160 objects (40 food items, 40 cars, 20 clothing items, 20 kitchen items, 20 plants, and 20 tools) and the NoGo stimuli consisted of 40 animals of varying visual typicality. These ranged from animals seen frequently in daily life, such as dogs and cats, to those seen less frequently such as lobsters and elephants. To decrease the reliance on perceptual cues when performing this task, features often seen in animals were decreased in presentation frequency in the animal condition and increased in the object condition. This was done based on item selection. Specifically, some animals were chosen that did not display features commonly used in animal identification, such legs (e.g., worm, butterfly, fish) and eyes (e.g., worm, lobster). For the objects, because there are no perceptual features that are common across the category of objects, the use of perceptual cues was minimized by increasing the occurrence of common animal features in the objects, such as including objects with legs (e.g., chair, table). Although this variation resulted to the inclusion of some less typical animals than were found in the Single and Multiple task, they were all still easily identifiable by young children. This task is identical to the adult study (Maguire et al. 2009) except that plants replaced body parts, which were included in the object condition of the previous study. This change was made because the body parts were difficult for children to differentiate from animals (both being “living things”). The images were from the standardized picture sets the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983) and Snodgrass and Vanderwart (1980) or were created in-house. All attempts were made to keep the images in a similar style to maintain similarity in visual complexity.

Procedure

Children came to the laboratory with their parents. Once consent was obtained and handedness was tested through performing a short set of everyday tasks (cutting paper, opening a bottle, kicking a ball, etc), the children watched a DVD of their choice as they were fitted with the 64 electrode Neuroscan QuickCap. Application was complete when impedances were below $10 \text{ k}\Omega$. The instructions were given before each task and identical across tasks with only the important object names changed, i.e., “You are going to see pictures of cars (objects) and dogs (animals). You are to press the button for all cars (objects) but do not press the button for anything else”. Instructions were given verbally, after which children were asked if they understood the task and given a chance to ask any questions about it. The instructions were also then displayed on the computer screen prior to each task. The three inhibition tasks were fully counterbalanced to remove any influence of increased or decreased difficulty within the testing session. For each of the three tasks, six randomizations were created to eliminate order effect within each task.

Data Acquisition and Preprocessing

Continuous EEG was recorded from 64 silver/silver-chloride electrodes mounted within an elastic cap (Neuroscan Quickcap) which are placed according to the International 10–20 electrode placement standard (Compumedics, Inc.). The data was collected using a Neuroscan SynAmps2 amplifier and Scan 4.3.2 software sampled at 1 kHz with impedances

typically below 10 k Ω . Blinks and eye movement were monitored via two electrodes, one mounted above the left eyebrow and one mounted below the left eye. The data were processed to remove ocular and muscle artifacts in the following way. First, poorly functioning electrodes were identified visually and removed. Second, eye blink artifacts were removed by a spatial filtering algorithm in the Neuroscan Edit software using the option to preserve the background EEG. Third, time segments containing significant muscle artifacts or eye movements were rejected. The continuous EEG data were band-pass filtered from 0.15 Hz to 30 Hz for analysis. The EEG data were segmented offline into epochs spanning 100 ms before to 1200 msec after the presentation of the visual stimuli.

Reference Correction

The data were recorded with the ground at AFz and the reference electrode located near the vertex, resulting in small amplitudes over the top of the head. In order to eliminate this effect, the data were re-referenced to the average potential over the entire head, which approximates the voltages relative to infinity (Nunez, 1981). In order to minimize a small bias in the electrode-based average reference (Junghöfer et al., 1999), a spline-based estimate of the average scalp potential (Ferree, 2006) was computed using spherical splines (Perrin et al., 1989). Placing the electrode cap on a realistic phantom head, the electrode coordinates were digitized (Polhemus, Inc.), and these coordinates were used to fit the splines for each subject. Subjects with a small number of bad electrodes, the splines were used to interpolate those electrodes, to yield a total of 62 data channels in every subject. Given children's limited attention span and the fact that our predications did not include information about source localization, this procedure was used instead of using the Polhemus on each of the children individually.

In calculating the ERPs, only items with correct responses and EEG portions with no movement artifacts were included. The mean number of epochs included in the participants average ERP per age per task is as follows, 7–8-year-olds Go Single: $M = 87.5$, $SD = 30.08$, Go Multiple: $M = 81.96$, $SD = 33.59$, Go Semantic: $M = 83.22$, $SD = 33.43$, 7–8-year-olds NoGo Single: $M = 13.27$, $SD = 6.37$, NoGo Multiple: $M = 12.8$, $SD = 5.8$, NoGo Semantic: $M = 10.6$, $SD = 5.4$, 9–10-year-olds Go Single: $M = 112.3$, $SD = 19.4$, Go Multiple: $M = 98.6$, $SD = 30.2$, Go Semantic: $M = 109.0$, $SD = 19.8$, 9–10-year-olds NoGo Single: $M = 17.1$, $SD = 6.9$, NoGo Multiple: $M = 15.4$, $SD = 8.5$, NoGo Semantic: $M = 16.8$, $SD = 6.2$. Thus, although there is variability in the error rates of participants across ages and tasks, this did not differentially influence the number of items included in the ERP analysis of each study.

ERP Calculation

For each correctly responded to trial and each electrode, the mean amplitude of the prestimulus interval (-100 ms -0 ms) was subtracted from each time point and those data were averaged across trials to create the ERP. The waveforms for midline frontal (Fz), central (Cz), and parietal (Pz) sites for each task for each age group can be seen in Figures 2 and 3. Because the goal of this paper is to identify patterns of results in early middle childhood and late middle childhood, as opposed to known changes such as amplitude and latency differences that occur with age, each age group was analyzed separately.

There is substantial variability across the field in terms of the electrode sites used to measure the P3 NoGo response in a Go/NoGo task (Azizian, Freitas, Parvaz, & Squires, 2006; Jonkman, Lansbergen, & Stauder, 2003; Kirmizi-Alsan et al., 2006; Proverbio, et al., 2009; Smith et al., 2007). Further, there is evidence that the P3NoGo response changes from centro-parietal to a more frontal distribution between the ages of 6 years and adulthood (Jonkman, 2006). Based on visual inspection of the current data for both age groups, the P3

NoGo response is largest over midline centro-parietal sites between 300–600 msec after stimulus presentation. This is what would be expected of a P3b response. Conversely, as can be seen in Figure 2, the frontal areas do not show a robust or consistent positive deflection to the NoGo items around 300 msec.

To compare differences between the Go and NoGo responses directly, the same electrodes needed to be taken into account. As a result, for Go compared to NoGo analyses, the average amplitude between 300–600 msec for Pz and CPz for each condition (Go, NoGo) was calculated. In identifying how task difficulty influenced each of the conditions, the P3 response was measured at its maximal location for Goes and NoGoes, which have been reported to have slightly different topographical distributions in children between 7–12 years of age (Johnstone et al., 2007). Figure 4 depicts these responses at midline electrodes that are included in both condition clusters (CPz and Pz). Because, the P3 Go response is maximal over both midline and lateralized centro-parietal areas the average amplitude of the Go response for each task was calculated between 300–600 msec at central and parietal sites (Pz, P1, P2, CPz, POz, CP1, CP2, P3, P4, P5, P6). Because the NoGo response is maximal over more midline, central and parietal areas in our data and previous reports using similar age groups (Johnstone et al., 2007), we calculated the amplitude of NoGo response across the three tasks between 300–600 msec over the following electrode sites (Pz, P1, P2, CPz, CP1, CP2, Cz, C1, C2).

Results

Behavioral Results

Errors of Omission—An error of omission is a failure to respond to a Go item. To determine this tendency across tasks, a 2 (Age Group) $\times$ 3 (task: Single, Multiple, Semantic) mixed factors ANOVA was performed on the errors of omission. A higher percentage represents more errors of omission. The analysis revealed no significant differences interactions or main effects. See Table 1 for a summary of all of the behavioral results.

Errors of Commission—An error of commission is responding with a button press to a NoGo item. A higher percentage indicates more errors. To calculate this tendency across tasks a 2 (Age Group) $\times$ 3 (task: Single, Multiple, Semantic) mixed factors ANOVA on the percent of incorrect NoGo items. No significant interactions or main effects were found. However, the main effect of task approached significance, $F(2, 35) = 2.815$, $p = 0.074$. Based on the means and the predicted results, post hoc contrast analyses were performed, which revealed the Single and Semantic tasks were significant different from one another, $F(1,36) = 4.825$, $p = 0.035$, but no other comparisons reached significance.

Reaction Times—Reaction times were calculated for correct Go responses. To calculate this tendency across tasks a 2 (Age Group) $\times$ 3 (task: Single, Multiple, Semantic) mixed factors ANOVA on reaction times was performed. This analysis revealed a significant main effect of task, $F(2, 35) = 13.10$, $p < 0.0001$. Post hoc contrasts revealed that responses to the Single items were significantly faster than Semantic, $F(1,36) = 26.07$, $p < 0.001$, but the other means are not statistically different.

Event Related Potentials: Amplitude

Go/NoGo Differences—The first issue was to identify amplitude differences between the Go and NoGo responses for each of the inhibition tasks. A 2 (age group) $\times$ 3 (Task: Single, Multiple, Semantic) $\times$ 2 (Condition: Go, NoGo) mixed factors ANOVA revealed a significant 2-way interaction between task and condition, $F(2, 70) = 3.78$, $p = 0.033$ and a main effect of condition, $F(1, 35) = 16.60$, $p < 0.0001$.

To investigate the 2-way interaction between task and condition, the age groups were collapsed and individual paired-samples *t*-tests were performed for each study comparing Go and NoGo responses. These revealed significant differences between the Go and NoGo amplitudes for the Single, $t(36) = 3.323$, $p = 0.002$ and the Multiple tasks, $t(36) = 4.028$, $p < 0.001$ but not the Semantic task, $t(36) = 1.41$, $p = 0.17$.

Task Differences—A 2 (age group) $\times$ 3 (Task) $\times$ Condition (Go vs NoGo) mixed factors ANOVA revealed a significant interaction between task and condition, $F(2,35) = 6.60$, $p = 0.004$, as well as an interaction between task and age that approached significance, $F(2, 70) = 3.147$, $p = 0.056$ and a main effect of condition, $F(1, 35) = 6.65$, $p = 0.014$. To tease apart how these differences relate to developmental changes in middle childhood, each age group was analyzed independently.

To identify differences in the Go response for each task in the 7–8 year olds, we performed a repeated-measures ANOVA comparing the amplitude across tasks. This revealed a significant effect, $F(2, 15) = 3.95$, $p = 0.042$. Post-hoc contrasts revealed that the amplitudes increased with task complexity, with the Simple task showing a lower amplitude compared to the Semantic task, $F(1,16) = 4.42$, $p = 0.052$, with no other differences between conditions near significance. No significant differences or trends were found in the NoGo responses for 7–8 year olds, $p > 0.90$.

Based on a one-way repeated measures ANOVA, the P3 Go response elicited by 10–11 year olds revealed no significant differences between tasks, $p > 0.60$. However, a repeated-measures ANOVA on the amplitude of the NoGo responses revealed significant between task differences, $F(2, 18) = 2.92$, $p = 0.036$. Based on the trends observed in the peak amplitudes we performed contrast analyses, which revealed significant differences between Single and Semantic, $F(1, 19) = 4.77$, $p = 0.042$, and Multiple and Semantic $F(1,19) = 5.647$, $p = 0.028$, but no differences between Single and Multiple, $p > 0.65$. These significant differences are noted in Figure 5.

Event Related Potentials: Latency

The latency of the P3 Go response was calculated as the average of the peak amplitude between 300–600 ms at central and parietal sites for each subject for each condition. The latency of the P3 NoGo response was calculated as the average of the peak amplitude between 300–600 ms at midline centro-parietal sites for each subject for each condition. A 2 (age group) $\times$ 3 (task: Single, Multiple, Semantic) $\times$ 2 (Go vs NoGo) mixed factors ANOVA revealed a significant effect of condition, $F(1, 35) = 6.767$, $p = 0.014$, with Go amplitudes peaking slightly earlier than NoGo amplitudes.

Discussion

The goal of this paper was to uncover how response inhibition is influenced by categorization in middle-childhood. These findings reveal that the categorization demands underlying a response inhibition task exert unique influences on the behavioral and ERP correlates of inhibitory processing in early and later middle-childhood. Behaviorally, both age groups showed significant increases in reaction times as the tasks became conceptually more difficult. Further, both age groups displayed the P3 Go/NoGo response for the Single and Multiple tasks, both of which could be performed using perceptual features, but not the Semantic task which required abstract, superordinate categorization. Further analysis of these results revealed that these apparent similarities are driven by different patterns. Specifically, the older children display an attenuation of the P3 NoGo amplitude with increased categorization demands and no corresponding changes to the P3 Go response. The

younger children, on the other hand, show an increase in the P3 Go amplitude with increased task demand and no corresponding changes to the P3 NoGo response.

These data provide insight into how the underlying processes associated with response inhibition changes during development. The pattern displayed by the oldest children is similar to that reported in adults by Maguire et al (2009) using three nearly identical tasks. Specifically, the P3 NoGo amplitude is influenced by task difficulty but the P3 Go response is not. This pattern of responses likely reveals an efficient strategy for response inhibition by the older children. They appear to be effectively categorizing and filtering out, to some degree, the Go information and devoting greater attention to the less common NoGo trials. If this were not the case, the influence of task difficulty would likely be evident in both the Go and NoGo P3 responses. Interestingly, the pattern is not a linear decrease with difficulty. Instead, the two tasks that can rely on perceptual items or features, Single and Multiple, elicited higher P3 NoGo amplitudes than the one task that requires abstract categorization, Semantic.

Despite similarities in the ERP responses between 10–11 year olds and the previously reported adults (Maguire et al, 2009), it is important to note that there were differences in the reaction times, error rates, and P3 response latencies between the two groups. In fact, the 10–11 year olds reported here made nearly twice as many errors of omission, responded about 100 msec slower, and had P3 latencies nearly 200 msec slower than the previously reported adults (Maguire et al., 2009). Thus, children in late middle-childhood, like adults, may have the strategies in place to perform tasks that require both inhibition and categorization, but they are not yet at adult-like levels in speed and accuracy.

Seven and eight year old children revealed a different pattern of responses than their older counterparts. In this case, the influence of task difficulty was found only in the P3 Go responses. This indicates that younger children may be devoting more attentional resources to the common Go items, than to the NoGo items. For young children, this strategy may be appealing because an action, in the form of a button press, occurs for the Go items. This is more enjoyable than not responding. As a result, instead of focusing on when not to respond, as the older children and adults are, they focus on when to respond. This is similar to the conclusions made by Davis et al. (2003) when comparing P3 Go/NoGo responses in 6-year-olds and adults. Davis et al. found that the amplitude for the P3 Go and NoGo responses were nearly equal in children. From this, they concluded that children were attending equally to both conditions, unlike the adults who focused on only the NoGo items and thus displayed significantly larger NoGo response amplitudes. As is the case across the Go/NoGo literature, the current study differs from the Davis et al study in many important ways, most notably, the ratio of the Go and NoGo stimuli and the amount of categorization necessary to respond, either of which may have accounted for a lack of amplitude difference between Go and NoGo items in children. The Davis et al study uses a ratio of 50:50 as opposed to the 80:20 ratio that favors the Go response. Further, the Davis et al task required categorization across perceptually dissimilar items for the Go items (letters other than X) but not the NoGo items (the letter X). Interestingly, the current study similarly reported no differences in the Go/NoGo amplitudes in the Semantic task, which most closely resembles the Davis et al task in terms of categorization. Also, similar to Davis et al., this lack of a difference in young children seemed to be related to changes occurring in the Go items as opposed to the NoGo items. Thus, we propose that both our findings and Davis et al's findings are due to young children attending equally to Go and NoGo items. When the task becomes cognitively difficult, in these cases due to categorization of the Go items, the Go amplitudes are as large as the NoGo amplitudes for children.

Interestingly, task difficulty influences the P3 amplitude associated with each of the two conditions in very different ways. The P3 Go amplitude increases with task difficulty, but the P3 NoGo amplitude is attenuated with task difficulty. Such a difference is likely due to the underlying processes associated with the two conditions. Increases in the P3 Go amplitude have been associated with increases in attention (Bennington & Polich, 1999) and for younger children, who are focused on the Go responses, more attention may be necessary for the more difficult tasks. Attenuation of the P3 NoGo amplitude has been linked to inhibiting conceptually or semantically complex items (Maguire et al., 2009; Schapkin et al., 2006). Interestingly, the result of these conflicting patterns of responses is that, when only comparing Goes to NoGoes without comparing across tasks, the two age groups appear to be performing in a similar manner. The actual developmental changes in attention and inhibition are only evident when comparing across tasks.

Although the different patterns displayed by the two age groups provide evidence of different cognitive processing underlying their behaviors, there are some limitations in this study that should be addressed in future work. One is that our selection criteria of having at least 30 clean, correctly responded to NoGo items across the three tasks resulted in the removal of data from a large number of participants (excluding twelve of the twenty-nine 7–8 year olds and five of the twenty-five 10–11 year olds). Especially concerning the younger age group, our results may reflect the abilities of 7–8 year olds with relatively advanced inhibitory skills instead of the average child at this age.

A second potential limitation was essential to the study design. To assure that the Single task required no categorization, the stimuli are each repeated on every trial, 160 times for the Go trials and 40 times for the NoGo trials. On the other hand, to assure that categorization was necessary in the Semantic task, none of the trials are repeated, each being completely novel to the participant. Both novelty and repetition are known to influence the P3 amplitude. In adults, novel items induce an increased P3 response, that is further increased with the repetition of that novel item (Cycowicz & Friedman, 1998). However, in those cases, the novel items had never been encountered before. By using known animals and objects and including only those items that were correctly identified by the participants, we removed the influence of novelty in this sense. Repetition of familiar items results in a decrease in the P3 amplitude (Courchesne, Courchesne, & Hillyard, 1978; Friedman, Hamberger, & Ritter, 1993; Polich, 1989; Rugg & Doyle, 1994; Rugg, Furda, & Lorist, 1988). For the older children reported here, as well as the adults in Maguire, et al (2009), the NoGo P3 amplitude changes in the opposite manner, with the Single task exhibiting the highest P3 amplitude. Thus, repetition and novelty cannot be the primary sources of these amplitude differences in the older children. It is possible, however, that repetition is influencing the increase in the P3 Go responses to the Single task that is observed in our younger ages. It seems unlikely, but not impossible that this influence would be seen in our younger children and not the older children. Future research will be necessary to tease apart these potential influences.

In conclusion, previous studies have reported differences in the behavioral and electrophysiological correlates of response inhibition that are proposed to be the result of variations in the specific tasks underlying the inhibition measures. By comparing across three different Go/NoGo tasks that differed only in the level of categorization needed to respond, we have uncovered important information about how response inhibition develops in middle-childhood. At younger ages, these results indicate that children may be focused on determining which items should result in a Go response as opposed to looking for which items require a NoGo response. By late middle-childhood, children appear to focus on identifying the less common items, which require one to withhold a response. Although the overall error rates and P3 Go vs NoGo responses looked quite similar between the age groups, the comparison across tasks revealed these differences. These results are important

to our understanding of the developmental changes in inhibition that occur in middle-childhood and may be of particular interest in studying children with inhibitory deficits such as Attention Deficit Disorder.

Acknowledgments

The authors would like to thank Dr. John Hart, Patricia Moore, Rebecca Egbert, and Diane Ogiela for their help in study design and analysis. The funding for this project was provided by a grant from the Sparrow Foundation for the CAARTE program and NIH (NINDS) K02NS044850 and R01NS047781.

References

- Azizian A, Freitas AL, Parvaz MA, Squires MK. Beware misleading cues: Perceptual similarity modulates the N2/P3 complex. *Psychophysiology*. 2006; 43:253–260. [PubMed: 16805863]
- Barkley RA, Edwards G, Laneri M, Fletcher K, Metevia L. Executive functioning, temporal discounting, and sense of time in adolescents with attention deficit hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD). *Journal of Abnormal Child Psychology*. 2001; 29:541–556. [PubMed: 11761287]
- Barry RJ, Johnstone SJ, Clarke AR. Electrophysiology in attention-deficit/hyperactivity disorder: II. Event-related potentials. *Clinical Neurophysiology*. 2003; 114:184–198. [PubMed: 12559225]
- Batty M, Taylor MJ. Visual categorization during childhood: An ERP study. *Psychophysiology*. 2002; 39(4):482–490. [PubMed: 12212640]
- Bennington JY, Polich J. Comparison of P300 from passive and active tasks for auditory and visual stimuli. *International Journal of Psychophysiology*. 1999; 34:171–177. [PubMed: 10576401]
- Brocki KC, Bohlin G. Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology*. 2004; 26:571–593. [PubMed: 15456685]
- Bruin KJ, Wijers AA, van Staveren ASJ. Response priming in a go/nogo task: Do we have to explain the go/nogo N2 in terms of response activation instead of inhibition? *Clinical Neurophysiology*. 2001; 112(9):1660–1671. [PubMed: 11514249]
- Ciesielski KT, Harris RJ, Cofer LF. Posterior brain ERP patterns related to the go/no-go task in children. *Psychophysiology*. 2004; 41:882–892. [PubMed: 15563341]
- Courchesne E, Courchesne RY, Hillyard SA. The effects of stimulus deviation on P3 waves to easily recognized stimuli. *Neuropsychologia*. 1978; 16:189–199. [PubMed: 692843]
- Cragg L, Nation K. Go or nogo? Developmental improvements in the efficiency of response inhibition in mid-childhood. *Developmental Science*. 2008; 11(6):819–827. [PubMed: 19046150]
- Cycowicz YM, Friedman D. Visual novel stimuli in an ERP novelty oddball paradigm: Effects of familiarity on repetition and recognition memory. *Psychophysiology*. 2007; 44:11–29. [PubMed: 17241137]
- Davis EP, Bruce J, Snyder K, Nelson CA. The X-trials: Neural correlates of an inhibitory control task in children and adults. *Journal of Cognitive Neuroscience*. 2003; 15(3):432–443. [PubMed: 12729494]
- Durston S, Thomas KM, Yang Y, Ulug AM, Zimmerman RD, Casey BJ. A neural basis for development of inhibitory control. *Developmental Science*. 2002; 5(4):F9–F16.
- Ferree TC. Spherical splines and average referencing in scalp EEG. *Brain Topography*. 2006; 19(1/2): 43–52. [PubMed: 17019635]
- French, R. The subtlety of sameness: A theory and computer model of analogy making. Cambridge, MA: MIT Press; 1995.
- French R, Mareschal D, Mermillod M, Quinn PC. The role of bottom-up processing in perceptual categorization by 3- to 4-month-old infants: Simulations and data. *Journal of Experimental Psychology: General*. 2004; 133(3):382–397. [PubMed: 15355145]
- Friedman D, Hamberger M, Ritter W. Event-related potentials as indicators of repetition priming in young and older adults: Amplitude, duration, and scalp distribution. *Psychology & Aging*. 1993; 8:120–125. [PubMed: 8461109]

- Friedman NP, Miyake A. The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*. 2004; 133:101–135. [PubMed: 14979754]
- Goldstone RL, Barsalou LW. Reuniting perception and conception. *Cognition*. 1998; 65:231–262. [PubMed: 9557384]
- Jodo E, Kayama Y. Relation of negative ERP component to response inhibition in a Go/No-go task. *Electroencephalography and Clinical Neurophysiology*. 1992; 82:477–482. [PubMed: 1375556]
- Johnstone SJ, Dimoska A, Smith JL, Barry RJ, Pleffer CB, Chiswick D, Clarke AR. The development of stop-signal and Go/Nogo response inhibition in children aged 7–12 years: Performance and event-related potential indices. *International Journal of Psychophysiology*. 2007; 63:25–38. [PubMed: 16919346]
- Johnstone SJ, Pleffer CB, Barry RJ, Clarke AR, Smith JL. Inhibitory processing during the Go/Nogo task: A behavioral and event-related potential study of children and adults. *Journal of Psychophysiology*. 2005; 19:11–23.
- Jonkman L. The development of preparation, conflict monitoring and inhibition from early childhood to young adulthood: a Go/Nogo ERP study. *Brain Research*. 2006; 1097:181–193. [PubMed: 16729977]
- Jonkman L, Lansbergen M, Stauder JEA. Developmental differences in behavioral and event-related brain responses associated with response preparation and inhibition in a go/nogo task. *Psychophysiology*. 2003; 40:752–761. [PubMed: 14696728]
- Jungthöfer M, Elbert T, Tucker DM, Braun C. The polar average reference effect a bias in estimating the head surface integral in EEG recording. *Clinical Neurophysiology*. 1999; 110(6):1149–1155. [PubMed: 10402104]
- Kincses TZ, Chadaide Z, Varga ET, Antal A, Paulus W. Task-related temporal and topographical changes of cortical activity during ultra-rapid visual categorization. *Brain Research*. 2006; 1112:191–200. [PubMed: 16928365]
- Kirmizi-Alsan E, Bayraktaroglu Z, Gurvit H, Keskin YH, Emre M, Demiralp T. Comparative analysis of event related potentials during Go/NoGo and CPT: Decomposition of electrophysiological markers of response inhibition and sustained attention. *Brain Research*. 2006; 1104:114–128. [PubMed: 16824492]
- Levin HS, Culhane KA, Hartmann J, Evankovich K, Mattson AJ, Harward H, et al. Developmental changes in performance on tests of purported frontal lobe functioning. *Developmental Neuropsychology*. 1991; 7:377–395.
- Lindqvist S, Thorell LB. Brief Report: Manipulation of task difficulty in inhibitory control tasks. *Child Neuropsychology*. 2009; 15:1–7. [PubMed: 18608218]
- Liston C, Watts R, Tottenham N, Davidson MC, Niogi S, Ulug AM, Casey BJ. Frontostriatal microstructure modulates efficient recruitment of cognitive control. *Cerebral Cortex*. 2006; 16(4): 553–560. [PubMed: 16033925]
- Maguire MJ, Brier MR, Moore PS, Ferree TC, Ray D, Mostofsky S, Hart J Jr, Kraut MA. The influence of perceptual and semantic categorization on inhibitory processing as measured by the N2-P3 inhibitory responses. *Brain and Cognition*. 2009; 71(3):196–203. [PubMed: 19773108]
- Mandler J, Bauer P, McDonough L. Separating the sheep from the goats: Differentiating global categories. *Cognitive Psychology*. 1991; 23:263–298.
- Murphy GL, Kaplan AS. Feature distribution and background knowledge in category learning. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*. 2000; 53A: 962–982.
- Nigg JT. On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*. 2000; 126(2): 220–246. [PubMed: 10748641]
- Nunez PL. A study of origins of the time dependencies of scalp EEG: II– Experimental support of theory. *IEEE Transactions on Bio-Medical Engineering*. 1981; 28:281–288. [PubMed: 7228074]
- Opitz, B. ERP and fMRI correlates of target and novelty processing. In: Polich, J., editor. *Detection of Change: Event-related potential and fMRI findings*. Norwell, MA: Kluwer Academic Publishers; 2003. p. 117–132.

- Perrin F, Pernier J, Bertrand O, Echallier JF. Spherical splines for scalp potential and current density mapping. *Electroencephalography and Clinical Neurophysiology*. 1989; 72:184–187. [PubMed: 2464490]
- Polich J. Habituation of P300 from auditory stimuli. *Psychobiology*. 1989; 17:19–28.
- Polich, J. Theoretical overview of the P3a and P3b. In: Polich, J., editor. *Detection of Change: Event-related potential and fMRI findings*. Norwell, MA: Kluwer Academic Publishers; 2003. p. 83-98.
- Proverbio AM, Del Zotto M, Crotti N, Zani A. A no-go related prefrontal negativity larger to irrelevant stimuli than are difficult to suppress. *Behavioral and Brain Functions*. 2009; 5(25):1–11. [PubMed: 19121215]
- Rosch E, Mervis CB, Gray WD, Johnson DM, Boyes-Braem P. Basic objects in natural categories. *Cognitive Psychology*. 1976; 8:382–439.
- Rubia K, Smith AB, Woolley J, Nosarti C, Heyman I, Taylor E, Brammer M. Progressive increase of frontostriatal brain activation from childhood to adulthood during Event-Related tasks of cognitive control. *Human Brain Mapping*. 2006; 27(12):973–993. [PubMed: 16683265]
- Rugg, MD.; Doyle, MC. Event-related potentials and stimulus repetition in direct and indirect tests of memory. In: Heinze, HJ.; Munte, TF.; Mangun, GR., editors. *Cognitive Electrophysiology*. Boston: Birkhauser; 1994.
- Rugg MD, Furda J, Lorient M. The effects of task on the modulation of event-related potentials by word repetition. *Psychophysiology*. 1988; 25:55–63. [PubMed: 3353486]
- Schapkin SA, Falkenstein M, Marks A, Griefahn B. Executive brain functions after exposure to nocturnal traffic effects of task difficulty and sleep quality. *European Journal of Applied Physiology*. 2006; 96:693–702. [PubMed: 16421758]
- Schumacher R, Wirth M, Perrig WJ, Strik W, Koenig T. ERP correlates of superordinate category activation. *International Journal of Psychophysiology*. 2009; 72(2):134–144. [PubMed: 19087886]
- Schyns PG, Goldstone RL, Thibaut JP. The development of features in object concepts. *Behavioral and Brain Sciences*. 1998; 21:1–54. [PubMed: 10097010]
- Shilling VM, Chetwynd A, Rabbitt PMA. Individual inconsistency across measures of inhibition: An investigation of the construct validity of inhibition in older *adults*. *Neuropsychologia*. 2002; 40:605–619. [PubMed: 11792402]
- Shue KL, Douglas VI. Attention deficit hyperactivity disorder and the frontal lobe syndrome. *Brain and Cognition*. 1992; 20:104–124. [PubMed: 1389116]
- Smith JL, Johnstone SJ, Barry RJ. Effects of pre-stimulus processing on subsequent events in a warned Go/NoGo paradigm: Response preparation, execution and inhibition. *International Journal of Psychophysiology*. 2006; 61(2):121–133. [PubMed: 16214250]
- Smith JL, Johnstone SJ, Barry RJ. Response priming in the GO/NoGo task: The N2 reflects neither inhibition nor conflict. *Clinical Neurophysiology*. 2007; 118(2):343–355. [PubMed: 17140848]
- Smith JL, Johnstone SJ, Barry RJ. Movement-related potentials in the Go/NoGo task: The P3 reflects both cognitive and motor inhibition. *Clinical Neurophysiology*. 2008; 119:704–714. [PubMed: 18164657]
- Tanaka JL, Luu P, Weisbrod M, Kiefer M. Tracking the time course of object categorization using event-related potentials. *NeuroReport*. 1999; 10(4):829–835. [PubMed: 10208556]
- Thorpe SJ, Fize D, Marlot C. Speed of processing in the human visual system. *Nature*. 1996; 381:520–522. [PubMed: 8632824]
- VanRullen R, Thorpe SJ. The time course of visual processing: From early perception to decision-making. *Journal of Cognitive Neuroscience*. 2001; 13:454–461. [PubMed: 11388919]
- Velanova K, Wheeler ME, Luna B. The maturation of task set-related activation supports late developmental improvements in inhibitory control. *The Journal of Neuroscience*. 2009; 29(40):12558–12567. [PubMed: 19812330]
- Wiersema R, van der Meere J, Roeyers H, Van Coster R, Baeyens D. Event rate and event-related potentials in ADHD. *Journal of Child Psychology and Psychiatry*. 2006; 47:560–567. [PubMed: 16712632]
- Williams BR, Ponesse JS, Schachar RJ, Logan GD, Tannock R. Development of inhibitory control across the life span. *Developmental Psychology*. 1999; 35:205–213. [PubMed: 9923475]

	Go		No Go	
Single (repeated)
Multiple (examples)
Semantic (examples)

Figure 1.
Stimuli used in each of the three inhibition tasks.

Figure 2.

Average ERPs for Go (solid) and NoGo (dashed) responses elicited by 7–8 year olds across all three tasks at 3 midline electrode sites, Fz (frontal), Cz (central), and Pz (parietal). The arrow and star identify significant difference between the Go and NoGo amplitudes.

Figure 3.

Average ERPs for Go (solid) and NoGo (dashed) responses elicited by 10–11 year olds across all three tasks at 3 midline electrode sites, Fz (frontal), Cz (central), and Pz (parietal). The arrow and star identify significant difference between the Go and NoGo amplitudes.

Figure 4. Average ERPs for Single (black), Multiple (grey), and Semantic (dashed) responses elicited by 7–8 year olds for Go (left) and NoGo (right) responses. The arrow and star identify significant differences between the amplitudes for the three tasks.

Figure 5. Average ERPs for Single (black), Multiple (grey), and Semantic (dashed) responses elicited by 10–11 year olds for Go (left) and NoGo (right) responses. The arrow and star identify significant differences between the amplitudes for the three tasks.

Table 1

Mean percent errors, reaction times, and standard deviations for each task with standard deviations.

	Single	Multiple	Semantic
7–8 yrs			
Go	10.7% (11.8)	11.8% (11.5)	11.0% (10.5)
NoGo	35.7% (20.1)	36.5% (16.6)	48.7% (16.7)
Reaction Time	450.9 (6.0)	471.5 (3.7)	500.4 (7.7)
10–11 yrs			
Go	6.33% (5.5)	10.4% (12.7)	8.5% (8.1)
NoGo	40.0% (19.5)	39.2% (22.6)	40.3% (15.1)
Reaction Time	394.2 (10.1)	412.6 (13.8)	454.5 (11.5)