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Brain and behavior correlates of a child's approach to learning: Studying persistence, executive functioning, and motivation in elementary students

A thesis submitted in partial satisfaction
of the requirements for the degree Master of Arts
in Education

by

Sarah Jo Torgrimson

2018

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ABSTRACT OF THE THESIS

Brain and behavior correlates of a child's approach to learning: Studying persistence, executive functioning, and motivation in elementary students

by

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Master of Arts in Education

University of Los Angeles, Los Angeles, 2018

Professor Jennie Katherine Grammer, Chair

Research suggests executive function (EF) skills are critical for early academic success (Blair & Razza, 2007), yet less is known about their relation to other factors of student performance, such as persistence (LiGrinning, et al., 2010). Combining approaches from developmental cognitive neuroscience and educational psychology, the current study investigated the relation between student's EF and factors of motivation on student performance. Students (N=84, Boys=33, M_{age}=6.94 years) were assessed on a battery of cognitive measures including measures of brain and behavioral correlates of EF. Student persistence during a challenging puzzle task, as well as intrinsic value and perceived competence for the task, were also measured. Findings indicate that persistence moderates the correlation between EF and persistent behavior. Thus, children who report high competency and have higher EF also show high persistent behavior. Additional findings revealed that that relation between EF and persistence across behavioral and neural levels differed by gender.

The thesis of Sarah Jo Torgrimson has been approved.

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2018

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Brain and behavior correlates of a child's approach to learning: Studying persistence, EF, and motivation in elementary students

As children enter school, they are faced with a host of new challenges such as focusing and sustaining their attention, monitoring their behavior and understanding, and remembering directives and instructions from their teachers (McClelland, et al., 2006). In order to successfully meet these challenges, it is posited that students must enter the classroom prepared with a certain level of proficiency in basic cognitive and social emotional skills (Blair & Razza, 2007). Reflecting this, the California First Five Initiative defines child readiness for the classroom across multiple aspects of well-being, including the development of motor and physical, social emotional, language, and cognitive skills as well as children's approaches to and feelings about learning, including enthusiasm, curiosity, and persistence (California Childcare Health Program, 2006). Notably, more positive overall approaches to learning are associated with better academic performance both at school entrance and across schooling (Li-Grinning, Votruba-Drzal, Maldono-Carreño, & Haas, 2010; Newman, Noel, Chen, & Mastopoulos, 1998; Jozsa & Morgan, 2013).

There are a number of factors that influence students' approaches to learning above and beyond cognitive skill. One aspect of motivation that might be particularly relevant to academic success includes a student's ability to expend repeated effort despite academic struggles or difficulty, formally termed persistence (Berhenke, Miller, Brown, Seifer, & Dickstein, 2011). Children with high persistent behavior show greater progression in academics (Li-Grinning, et al., 2010; Martin, Ryan, Brooks-Gunn, 2013) and degree attainment (McClelland, Acock, Piccin, Rhea, & Stallings, 2013) as well as the ability to improve their overall academic grade point average (Jozsa & Morgan, 2013). Field research on contextual factors of motivation, have shown

that aspects of a student's environment can support persistence, such as creating classrooms that support autonomy, perceived competence, and social relatedness (Ryan & Deci, 2000). However, it is unclear how aspects of cognition and motivation interact when cognitive and regulatory skills are first emerging in early schooling (Blair & Raver, 2015).

Recent advances in neuroscientific methods allow for relatively inexpensive exploration of brain activity associated with aspects of learning that are otherwise challenging to observe through assessments of behavior alone. Neural indicators of cognitive skills can be utilized to uncover individual differences in processes that underlie variation in academic achievement (Hillman, et al., 2012) and motivation (Moser, et al., 2011). Moreover, utilizing a multi method approach, incorporating brain and behavior offers a broader depiction of the relation of these skills (Anderson, 2002), especially as students may be more motivated when testing one-on-one with an experimenter than in typical day-to-day classroom practices (Berhenke, et al., 2011).

Recently, researchers have begun to examine the relations between children's motivation and executive function (EF) skills using neural markers that are sensitive enough to expose a wide range of individual differences in students' cognitive performance (Kim, Marulis, Grammer, Morrison, & Gehring, 2017). These neural markers reflect cognitive control processes that are related to children's ability to monitor their performance, to identify when they have made an error, and to adjust their behavior accordingly to improve their performance (Grammer, Carrasco, Gehring, & Morrison, 2014). It is possible that these same neural markers may also predict children's ability to persist on a challenging cognitive task, where they are required to monitor their performance and maintain motivation despite error. As of yet, however, little work has investigated how these neural markers of cognitive processes relate to persistence.

Thus, employing behavioral and neuroscientific methods, the purpose of the current study was to examine the relationship between early elementary students' persistence and EF skills in a school-based investigation. Understanding how EF and persistence relate to one another, including assessments of brain and behavior, may bring us closer to understanding the mechanism supporting the development of academic skills in early elementary school.

Approaches to Learning

Children's ability to attend to different environmental cues and inhibit distractors to appropriately engage with a task is related to their level of executive functioning (EF). Consequently, children's self-regulatory behavior is thought to largely reflect individual differences in EF. Evidence suggests, however, that children's engagement in learning activities – or approaches to learning – is also influenced by the coordination of several skills such as attention, emotion regulation, and persistence. In concert, these factors allow the child to appropriately regulate their thoughts, emotions, and behavior to meet the demands of the task (Fantuzzo, et al., 2007). Although theoretically linked to one another, these constructs, have been historically studied independently and the mechanism of how EF supports engagement, persistence, and flexibility is still unknown (Newman, et al., 1998).

A positive overall approach to learning is described as the ability to work well independently or with a group, and demonstrate eagerness to learn, self-control, organization, and persistence in the classroom (Li-Grinning, et al., 2010). Students who have more positive approaches to learning typically have higher math and reading skills and children with more positive approaches to learning early in school experience greater growth in their academic skills (Li-Grinning, et al., 2010). Some studies suggest that persistent behavior alone may serve as early indicators of children's academic trajectories (Newman, et al., 1998). As such, individual

differences in persistence may serve as an appropriate outcome measure to represent a student's approach to learning and level of engagement with a learning paradigm.

Persistence

Persistence is defined as an adaptive approach to learning indicative of a child's ability to focus and resist distractors (Vitiello, Greenfield, Munis, & George, 2011) and demonstrate continue effort despite cognitive challenge or difficulty (Berhenke, et al., 2011). Measures of persistence are associated with teacher reports of students' academic competencies as well student social and self-regulation skills (Berhenke, et al., 2011). In order to assess persistence, researchers often utilize a set of novel puzzles or trivia games to observe children's approaches to challenge (Smiley & Dweck, 1994). In one study employing these methods, preschool children's persistence on a challenging puzzle task was found to predict performance on standardized measures of math, literacy, and language proficiency when they were in kindergarten (Mokrova, O'Brien, Calkins, Leerkes, & Marcovitch, 2013). This finding suggests that duration of persistence is a valid indicator of a child's early adaptive approach to learning and that longer engagement with a challenging, but achievable, task benefits acquisition of academic material.

While persistence is correlated with academic performance across schooling, a child's persistence can fluctuate both by context (Ryan & Deci, 2000) and over time (Jozsa & Morgan, 2013). Self-determination theory (SDT) integrates aspects of motivation and an individual's ability to utilize their resources in order to learn from their environment and exhibit appropriate levels of regulated behavior (Ryan, Kuhl, & Deci, 1997). SDT highlights three basic psychological needs that drive an individual's self-motivated behavior – need for competence, relatedness, and autonomy. Subsequently, research supporting SDT indicates that persistence, an

aspect of motivated behavior, is greatest when children are in contexts that promote feelings of autonomy, competence, and social relatedness (Ryan & Deci, 2000). While the transition from childhood to adolescence is characterized by an increase in autonomy (Hill & Holmbeck, 1986), self-reported persistence has been shown to decrease overall from grades 4 to 8 for most students (Jozsa & Morgan, 2013). However, children that modified their approaches to learning and increased persistent behavior across the transition to middle school also saw related increases in academic performance (Jozsa & Morgan, 2013). This finding suggests that exploring ways to instill positive approaches to learning early on may aid children in maintaining or even improving academic performance (Cunha, Heckman, Lochner, & Masterov, 2006).

Research on persistence in early schooling relies heavily on parent or teacher-reports of student engagement with classroom or homework materials. These studies provide support for the relation between child persistence and academic performance in elementary school. Specifically, parent-reported student persistence has been linked to the acquisition of early reading skills (Newman, et al., 1998) as well as student achievement trajectories in math and reading across elementary school (Li-Grinning, et al., 2010). Notably, this effect was found for students from a wide range of socioeconomic and racial backgrounds and was particularly beneficial for students that entered kindergarten with initially low levels of reading and math skill. As early reading and math skills are related to later achievement (Reardon, 2011), persistence may be a particularly important behavioral tool for our highest risk students that enter school with lower academic skills. Understanding factors that relate to persistence, therefore, has important implications for primary school educators.

Persistence & Student Contextual Factors

As outlined above, environments that support autonomy, competency, and social relatedness have been shown to support persistent behavior in students (Ryan & Deci, 2000). Theory from both social and motivational psychology offers potential factors impacting the autonomy, competency, and social relatedness of a student's environment.

Motivational factors. Persistence is considered to be a measure of task (Berhenke, et al., 2011) and mastery motivation (Jozsa & Morgan, 2013) and is influenced by a child's self-imposed expectations and learning goals (Shunk, 1991). Several motivational theories support the integration of a student's expectations and interest in a task as impacting their level of engagement and persistence through task demands (Wigfield, Eccles, Schiefele, Roeser, & Davis-Kean, 2006; Shunk, 1991; Bandura 1986). A child's expectations for a task can also be thought of as their self-efficacy or belief that they can control their level of achievement on a task (Bandura, 1986). A student's self-efficacy, or perceived level of competence, is influenced by experiential factors such as children's prior experience with academic success or failure, their locus of control, and even expectations placed on individuals due to gender identification (Pajares, 1996; Ryan & Deci, 2000). Additionally, students who have higher self-efficacy typically demonstrate higher interest for a particular task. Theorists suggests this is due to previous successes in a particular domain influencing a child's level of self-satisfaction and accomplishment, making children both interested in pursuing that domain and fairly confident in their competencies (Bandura, 1991). Supporting this, both a child's self-efficacy (McTigue & Liew, 2011; O'Neill & Thomson, 2013; Bandura, 1986) and interest level (Martin, Ryan, & Brooks-Gunn, 2013) have been shown to influence their level of persistence.

Earlier in schooling, a student's self-efficacy may be particularly impacted by experiences with academic performance, decreasing in response to failure and increasing in

response to success. However, self-efficacy becomes more stagnant over time and resilient to instances of failure (Bandura, 1986) signifying the importance of promoting high self-efficacy and competencies in young students. Thus, it is important to understand the development of self-efficacy in conjunction with persistence and other cognitive skills (EF) when self-efficacy is still malleable and susceptible to environmental influences. In particular, aspects of motivation and persistence may be influenced by student gender, due to differences in gender socialization and associated performance expectancies.

Gender Socialization and Performance Expectations. A student's belief about their ability to successfully complete a task is influenced by both external evaluations and self-evaluations of previous performances. In early schooling, teachers provide this external feedback to help children regulate their effort and develop these self-monitoring, or self-evaluating, abilities. However, reported differences have been found in the way teachers interact with children based on a child's gender that have implications for how children develop their expectations and values for a particular task. On average, adults tend to value girls who demonstrate good behavior and hard work, whereas adults value intellectual substance in boys (Dweck, et al., 1978). In elementary school in particular, girls (ages 7-12) receive greater praise for effort, whereas boys are praised for their ability (Koestner, 1989; Burnett, 2002; Corpus & Lepper, 2007). Girls receive signals from their teachers that they should value interpersonal relationships, and consequently, report better relationships with their teachers (Deci & Ryan, 1980). Boys are taught to value independence and achievement (Deci & Ryan, 1980) and, as such, report higher levels of perceived competence (Watt, 2007). In fact, teachers are more likely to attribute a child's failure to lack of ability if she is a girl and to lack of effort if he is a boy (Dweck, et al., 1978). In turn, boys more often attribute academic successes to high ability

(Lohbeck, Grube, & Moschner, 2017). Conversely, girls more often attribute academic success to effort and academic failure to low ability (Mok, Kennedy, & Moore, 2011; Dickhäuser & Meyer, 2006; Benölken, 2015).

Because of the reported gender differences in social relatedness and perceived competence, it is possible that gender socialization influences children's persistent behaviors. Given that girls are often taught to value interpersonal relationships and often report better social relationships with their teachers, we may see enhanced persistence in girls during a one-on-one evaluation with an experimenter. Additionally, due to higher reports of perceived competence in boys, boys may show greater persistence for a particular task when they also have high competency beliefs for that task. Initial evidence of these patterns comes from work indicating that persistence shows differential relevance for academic trajectories in math and reading as a function of a child's gender (Li-Grinning, et al., 2010). For girls, persistence is more related to academic trajectories in math, where stereotypically girls are considered to have lower abilities than boys and boys are considered to be of higher competence. For boys, however, persistence is more strongly correlated to academic trajectories in reading, where there are no preconceived gender-based stereotypes related to performance. Thus, for academic domains in which competence for boys is considered high, variations in general persistence do not seem to matter for academic trajectories, perhaps due to higher persistence in that specific domain. Whereas in a context where competence is perceived as low (math for girls) or non-specific (reading for boys), persistence may play a larger role in supporting children's academic success. This line of research indicates that gender stereotypes perpetuated by socialization practices may be playing a role in a student's expectations for their performance, which in turn impacts their motivation to demonstrate persistence.

Executive Functioning

While a child might be motivated to persist, differences in attentional and working memory capacities may modulate a child's ability to actively engage and persist for a duration of time when interacting with a challenging task. These cognitive skills fall under the umbrella term EF. EF is conceptualized as the cognitive components that support self-regulation including all behaviors related to appropriately adapting one's thoughts, emotions, and behaviors to continually meet the demands posed in the environment (Blair & Raver, 2014). While EF encompasses many skills, three main categories are distinguished in the literature: working memory (e.g. the ability to hold relevant information in mind), inhibitory control (e.g. the ability to ignore distractions), and shifting (e.g. the ability to adjust attention from one task to another; Shing, et al., 2010). Differences in EF skills are thought to underlie individual differences in self-regulation (Li-Grinning, et al., 2010) and may provide cognitive resources for students during tasks that require enhanced levels of engagement and persistence. Preliminary evidence of a relation between EF and persistence was found in a sample of preschool children, wherein teacher-reports of child engagement and persistence in the classroom mediated the relationship between EF and academic school readiness (Vitiello, et al., 2011). This finding suggests that EF skills may act as a cognitive support for children's capacity to demonstrate persistence, although the mechanism of how these skills might relate is still unknown.

In the field of neuropsychology, performance on EF tasks is often interpreted as an indirect measure of brain functioning in the prefrontal cortex (PFC; Bell & Wolfe 2007; Swingler et al., 2011). The PFC and the anterior cingulate cortex (ACC) support cognitive control processes and are activated during tasks requiring higher levels of cognitive processing (de Haan, 2014). Additionally, the rapid growth of EF in school-aged children is thought to

mirror the cortical growth in the PFC and ACC during this developmental period (Crone & Westenberg, 2011). In order to study EF and cognitive control processes across behavioral and neural measures, researchers draw from methodology and theory across multiple fields of study. As such, terminology and operational definitions for particular skills differ across each method used (see Table 1).

Measuring Child Functioning through an Interdisciplinary Approach

While EF is highly studied in the field of neuropsychology, in the field of cognitive neuroscience, the term for skills that allow children to regulate their attention and behavior is cognitive control (Anderson, 2002; Gehring, Liu, Orr, & Carp, 2012; see Table 1). Response monitoring, in particular, is defined as a form of active working memory that is involved in the encoding and updating of information and serves to allow the brain to piece out which incoming information is relevant to the task at hand and which information can be disregarded (Miyake et al., 2000). This skill has been linked to the ability to identify success or failure during task performance (Isquith, Roth, & Gioia, 2000) and is highly valuable during novel task learning as it allows individuals to modify their own behavior in order to improve their performance (Isquith et al., 2000). Therefore, it is possible that response monitoring may support persistent behavior. In order to investigate underlying brain functioning related to cognitive control, experimenters in the field of cognitive neuroscience measure children's neural responses during performance of computerized tasks tapping basic response monitoring or attention skills utilizing an event-related potential (ERP) technique.

Measuring Neural Activity

The neurons, or cells, in our brain communicate through electrochemical signals that produce a measurable electrical current. Electroencephalogram (EEG) is a method that allows

experimenters to non-invasively measure electrical activity in a child's brain by placing electrodes, or sensors, on the scalp, often through usage of an EEG cap. Continuous EEG activity can then be collected, similarly to the way in which the electrical activity of the heart is measured through the usage of electrocardiograms (EKG). A unique benefit of this methodology is that it is temporally sensitive and can measure immediate brain responses to events, on a millisecond time scale. In order to get a neural measure of a child's response monitoring ability, experimenters average the neural reactivity when a child makes an error and then assess components of interest within the average ERP (Pontifex, et al., 2010). Two components of interest are the error-related negativity (ERN) and error positivity (Pe) which conceptually reflect error detection and conscious evaluation of performance, respectively (Wiersema, van der Meere, & Roeyers, 2007).

The ERN is a negative neural component that occurs at frontocentral sites about 50 milliseconds after an error response has been made (for a review see Gehring, Liu, Orr, & Carp, 2012). According to conflict-monitoring theory, the ERN is resultant of a self-corrective mechanism, in which the brain is identifying a mismatch between the error response made and the known correct response (Yeung, Botvinick, & Cohen, 2004). As such, the ERN is greater (more negative) when the correct answer or response is readily known. Additionally, when the significance of making an error is perceived to be greater, the ERN is also a larger negative deflection (Maier & Steinhauser, 2016). Thus, the ERN is sensitive to both the context of and the motivation for performance.

A smaller negative peak to correct responses, known as the correct-response negativity (CRN) component, has also been found to relate to cognitive control performance (Grützmann, Riesel, Klawohn, Kathmann, & Endrass, 2014). Like the ERN, it occurs rapidly (within first 100

ms) after a response has been made, spurring debate in the literature to whether the ERN and CRN represent separate or related cognitive processes (Bartholow, et al., 2005). Some research suggests that the CRN reflects an attention cue to sustain engagement and avoid future errors (Luu, Flaisch, & Tucker, 2000) and may be enhanced when children are younger, decreasing into adulthood as a function of development (Clawson, Clayson, Keith, Catron, & Larson, 2017).

The Pe is a positive neural component that accompanies the ERN and occurs at centroparietal scalp sites approximately 200 to 500 milliseconds after an error response (for a review see Overbeek, Nieuwenhuis, & Ridderinkhof, 2005). The Pe captures a more delayed neural reaction to error and is thought to reflect attention allocated to the mistake made, i.e. a stronger (more positive) Pe when someone is highly aware they made an error (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001).

Both of these response monitoring ERPs (ERN and Pe) have been linked to behavioral measures of post-error slowing and task accuracy, indicating a connection between neural processing of errors and a child's ability to modify their task strategy (Torpey, Hajack, Kim, Kujawa, & Klein, 2012). Additionally, greater differences in neural reactivity to a correct vs. error response have been linked to more accurate performance on these computerized tasks assessing cognitive control skills related to aspects of EF (Torpey, et al., 2012), indicating that greater neural differentiation between correct and error responses are linked to better response monitoring and self-regulation skills. As such, it is particularly relevant to study neural differentiation of these EF components in relation to motivation when children's brains are undergoing a critical growth period and individual differences may be greatest, such as early elementary school. Recent research has shown that these neural markers can be observed in a

school-based investigation in children as young as 3-years-old and relate to young children's academic skills and perceived competence (Grammer, et al., 2014; Kim, et al., 2017).

Grounded Theory

Support for this methodology, combining measures of brain and behavior, comes from the Dynamic Systems Theory (DST; Smith & Thelen, 1998) and Probabilistic Epigenesis Theory (Gottlieb, 1992; 2006). DST conceptualizes development as continuously emerging and occurring at every level of interaction between a child and their environment such that changes in development can be seen across biological and psychological measurements. Similarly, probabilistic epigenesis frames development as bidirectional change imposed between physiological characteristics and psychological functioning. As such, probabilistic epigenesis considers both experience-expectant and experience-dependent processes. Children are expected to react and respond in a certain way to the environment (e.g. a classroom) based on current physiological characteristics, such as gene expression and brain functioning, that results in a psychological function (e.g. inattentiveness) that can be observed by a child's caregiver (e.g. teacher). However, a child's interaction with their environment (e.g. learning from their teacher) can help develop psychological functions (e.g. attention) which in turn also impose changes in gene expression and the functional connectivity in the brain.

Recent work suggests that schooling does in fact change brain functioning and patterns of neural activity (Brod, Bunge, & Shin, 2017) and reactivity (Grammer, et al. in prep) during cognitive engagement. Moreover, because many basic cognitive tasks were initially designed to assess EF skills in adults, these same tasks may not be measuring parallel constructs in children. Therefore, it is suggested that multiple methods of assessment be utilized for constructing EF skill capacities in children (Anderson, 2002), especially as assessment one-on-one may be more

motivated than performance in typical day-to-day practices (Berhenke, et al., 2011). As such, this investigation will analyze the relation between EF and persistence across assessments of both brain and behavior.

Current Study

The purpose of the current study is to examine the relationship between EF and task persistence for early elementary students in a school-based investigation. Students in kindergarten, first-, and second-grade were assessed on a battery of EF and cognitive control tasks and assessed both in terms of behavioral performance and neural activity. Two levels of behavioral performance were assessed 1) at a global level using the Head, Toes, Knees, Shoulders (HTKS; Ponitz, et al., 2008) task that requires the coordination of working memory, inhibitory control, and attention shifting skills and 2) a discrete level using a cognitive control computerized Go/No-Go task (Grammer, et al., 2014) tapping response monitoring skills. Neural activity was recorded using an electroencephalogram (EEG) cap during the computerized task in order to compute neural markers of response monitoring. A challenging puzzle paradigm similar to the one used in Smiley and Dweck (1994) was used to provide a measure of duration of task persistence. Descriptive information as well as student's level of intrinsic value and competence for the puzzle task was also collected in order to explore potential individual differences in motivation that impact the relation between EF and task persistence.

The first main research question of this project was:

1) *What student characteristics are related to student behavior? Specifically, will child gender, motivation (intrinsic value and perceived competence), or cognition (EF and response monitoring) be related to observed differences in duration of persistence for a challenging task?*

Due to gender differences in socialization, we expected that girls would persist regardless of performance, in order to maintain a positive relationship with the experimenter and meet the social expectation of showing hard work, despite challenge. We also hypothesized that a child's motivation to complete the task, as indexed by their intrinsic value and perceived competence, would impact their level of performance. Perhaps children with low competency about their ability to complete the task, may disengage faster as they face a challenging cognitive task due to their belief that they may fail (Murphy & Alexander, 2000). Thus, we expected that children with higher persistence would report higher perceived competence for the puzzle. In accord with previous work, we expected that children with greater persistence would also report higher levels of intrinsic value (Martin, Ryan, & Brooks-Gunn, 2013).

Further, we hypothesized that children with greater observed EF skills would show greater persistence in the face of challenge, due to better regulation of attention and working memory skills (Blair & Raver, 2014). Additionally, we expected neural indices of response monitoring to also predict task persistence. Conflict monitoring theory (Yeung, Botvinick, & Cohen, 2004) states that greater neural response to errors in relation to correct responses is an index of better task monitoring skills and therefore a better understanding of performance. Consequently, we hypothesized that children with greater ability to monitor their performance, as indexed by larger neural responses to error, would show greater persistence to cognitive challenge resulting in a longer duration of engagement as measured by task instruments.

The second focal question was:

2) How do aspects of students' cognition and motivational beliefs interact in relation to persistent behavior? Particularly, does the relation between children's cognitive skills (EF and

response monitoring) and persistence differ for children with high as opposed to low levels of intrinsic value or perceived competence?

As few studies have investigated the relation of school readiness skills in terms of individual assessment of performance, the novelty of the current study prevented us from drawing upon the literature to make specific hypotheses. However, it was expected that motivational factors of intrinsic value and persistence may be particularly important for persistence in children with low cognitive skills, where maintaining attention might be a particular challenge (Newman, et al., 1998). Therefore, it was hypothesized that children with low EF and cognitive control indices would show more persistent behavior if they reported higher intrinsic value or perceived competence. Alternatively, children with higher reports of perceived competence and intrinsic value may demonstrate high persistence regardless of level of EF.

Method

Participants

A total of 87 kindergarten, first-, and second-grade students were recruited from seven classrooms at a private laboratory school associated with a large public university in southern California. Students were recruited in two waves, one in the spring (N=41) and a second in the fall of 2017 (N=46). The racial composition of students who attend the school is reported as 36% Caucasian, 20% Latino, 12% Latino-Caucasian, 9% Asian, 5% Asian-Caucasian, 7% African American, 3% African American-Caucasian, and 8% Other. Reports for the 2017-2018 academic year demonstrate annual family incomes ranging from below \$10K to at or above \$1 million and indicate that the majority of families are upper middle class. The current sample reflects the diversity of the school with a sample that is 26.19% Caucasian, 14.29% Latino, 11.90% Latino-

Caucasian, 5.95% Asian, 3.57% Asian-Caucasian, 4.76% African American, 5.95% African American-Caucasian, and 2.38% Other. Additionally, 25% of students reported a racial background not represented by the overall school demographics: 4.76% Caucasian-Other, 4.76% African American-Latino-Caucasian, 3.57% African American-Caucasian-Other, 2.38% Latino-Asian, 2.38% Latino-Other, and 1.19% of children reported as African American-Asian, African American-American Indian, African American-Caucasian-Asian, African American-Caucasian-Asian-Other, Latino, Caucasian-Asian, and Caucasian-Pacific Islander. Annual family income in the sample is as follows: <\$10K (5.95%), \$10K-\$14.999K (1.19%), \$15K-\$19.999K (1.19%), \$20K-\$34.999K (4.76%), \$35K-\$49.999K (7.14%), \$50K-\$74.999K (4.76%), \$75K-\$99.999K (4.76%), \$100K-\$149.999 (5.95%), \$150K-\$199.999 (4.76%), \$200K-\$349.999K (23.81%), \$350K-\$499.999K (8.33%), \$500K-\$749.999K (8.33%), % \$750K-\$999.999K (4.76%), \$1 Mil or more (14.29%).

Recruitment was conducted in-person during school drop off hours, letters home, and online ‘backpack’ notes sent by the school to parents of eligible children, including all students currently enrolled in kindergarten, 1st or 2nd grade. Information packets included a letter from the principal investigator and supporting staff, two copies of the parent permission form, and an informational flyer about electrophysiological (EEG) recordings. Parental consent was obtained for all participating students. All recruitment and study procedures were approved by both the supporting university’s institutional review board and the IRB of the participating school. Participants and families did not receive compensation for study participation. However, information on research findings was shared with families and teachers via an electronic ‘backpack’ note.

Attrition in the sample was due to child compliance (N=2) and experimenter error (N=1). Thus, the current analysis of children's persistent behavior includes the assessment of 84 ($M_{\text{age}}=6.94$ years, $N_{\text{boys}}=33$) kindergarten (N=42), first (N=21), and second-grade (N=21) students. All available data was used for any given task, however, further exclusion within this sample is detailed below.

All 84 children are in the sample to examine the predictive relationship between global EF and persistence. Data from 64 children ($M_{\text{age}}=6.93$ years, $N_{\text{boys}}=27$) were assessed for relations between persistence and behavioral indicators of response monitoring skills. Two children did not reach above chance performance on the measure of response monitoring and were excluded from analyses. Additional data for the Go/No-Go task was lost due to child compliance, with children opting to stop halfway through the game most likely due to boredom (N=2) and software issues (N=3). For our analyses of neural correlates of response monitoring, lost data was due to both hardware issues (N=3) and software issues (N=14) with the EEG recording equipment, such that 3 children did not reach the minimum amount of 'clean' EEG data (6 epochs; Pontifex, et al., 2010) and in 14 cases, the computer program did not record appropriate triggers required to examine neural activity related to time-locked events. Thus, for the analyses regarding the relation between persistence and neural activity, 47 children ($M_{\text{age}}=6.94$ years, $N_{\text{boys}}=17$) are included in the sample.

Procedure

Participating students were engaged in two sessions of data collection during the school day. Signed student assent was collected at the beginning of both sessions. For wave one, the first session lasted approximately 30 minutes and was comprised of the Head, Toes, Shoulders, Knees task (HTKS; Ponitz, et al., 2008), a challenging puzzle task, and two motivation

assessments: a puppet interview and the Elementary School Motivation Scale (ESMS; Guay, Marsh, & Dowson, 2005). For wave two, the applied problems and letter word subscales of the Woodcock Johnson Academic Ability III (WJIII; Wendling, Schrank, & Schmitt, 2007) measure were also assessed, adding twenty minutes to procedure time for a total of 50 minutes. For the purposes of the current study, only the HTKS, puzzle task, and puppet interview are included as measures of interest and thus procedures for the ESMS and WJII are not detailed below.

The second session lasted approximately one hour and involved EEG recording. After assent, children were fitted with the EEG cap (actiCAP; Brain Products, Germany), a small amount of Signa Gel was applied to 30 scalp sites (Ag/AgCl) via the 10/20 system (Jasper, 1958), and 2 passive electrodes were placed below each pupil on children's cheeks to collect muscle movement from eye blinks. Children were then shown their EEG signal being recorded in order to enhance their knowledge about science and research, make them more comfortable about what data were being collected 'from their brains,' and alert the children to the importance of sitting as 'still as a statue' during collection in order to minimize muscle artifact. Students then completed a child friendly Go/No-Go task (Grammer, et al., 2014; McDermott, White, Degnan, Henderson, & Fox, under review), watched a short clip from the *Magic School Bus* (May, et al., 1996) for collection of resting state EEG activity, played a feedback version of the Go/No-Go task, and completed an emotion regulation task called Impossibly Perfect Circles (adapted from the LabTab; Gagne, et al., 2011). To reduce redundancy across tasks, for wave two, a new Go/No-Go task was created following the same task parameters but utilizing different stimuli. Due to the scope and focus of this paper, procedures for the Feedback version of the Go/No-Go task and Impossibly Perfect Circles task are not detailed.

Assessment of Executive Functioning

Go/No-Go Tasks. The Go/No-Go task was designed to be child-friendly, fun, and engaging. The task used for wave one is set in the context of a zoo where all the animals have escaped from their cages. Game instructions include a narrative introducing children to zoo keeper Melissa and her three orangutan friends. Children are asked to help Melissa and her orangutan friends "catch" all the zoo animals that have gotten out of their cages and help bring them home. Children are instructed to press a button on a video game controller whenever they see an animal, this is a "Go" trial, in which children must catch the animals "as fast as they can." Children are told not to press a button when they see the orangutan friends, a "No-Go" trial, in which children must inhibit the prepotent response to continue pressing a button at the flash of an animal stimuli. In wave two, the Go/No-Go task has a different narrative where children are instructed to help scuba diver Sam take pictures of sea creatures. The scuba game taps the same response inhibition skill as the zoo version of the Go/No-Go, with identical parameters, but with a different narrative. Children are instructed to press a button on a video game controller whenever they see a sea creature; this is a "Go" trial, in which children must take pictures of the sea creatures "as fast as they can." Children are told not to press a button when they see the blue tang fish, a "No-Go" trial, as these fish are sensitive to the camera flash. Both versions of the game consists of 320 trials (75% Go trials, 25% No-Go trials), presented for 500 ms. Children have 1000 ms to respond (see Figure 1). Accuracy is assessed three ways: the number of correct trials (Go trials in which the child pressed the button and No-Go trials in which the child did not press the button), incorrect trials (No-Go trials in which the child pressed the button, an error of commission), and errors of omission (Go trials in which the child did not press the button). Percentages for correct, incorrect, and errors of omission are calculated based on the proportion to the total number of trials (320). Inclusion criterion is performing above chance (60% correct).

Additionally, reaction time for correct (Go trials) and incorrect (No-Go trials) are calculated as an average response time (ms) from when the stimulus appears on the screen to when the child presses the button on the game controller.

Head, Toes, Knees Shoulders (HTKS). The HTKS is a task tapping children's behavioral regulation, attention, and working memory skills (Ponitz et al., 2008). Children first learn a set of associated word pairs (head/toes or shoulders/knees) and then, in round 1, are instructed to perform the opposite action of a prompt (i.e. *Touch your head when I say 'Touch your toes.'*). In round 2, children must remember four paired rules for behavior, touching head or shoulders when hearing toes or knees, respectively and vice versa. Round 3 is a challenge level, intended to allow for this measurement across a relatively broad age of development (3-8 years). The associated rules are all changed in Round 3, and children must inhibit previously paired rules (head/toes and knees/shoulders) in order to respond correctly with newly acquired rule pairs (knees/head and toes/shoulders). Each item is coded as follows: 0 = incorrect response, 1 = any motion to incorrect response, subsequently self-corrected to the correct response, 2 = correct response, and total score: the final score is the sum of the 17 practice items and the 30 test items (Range: 0-94).

Assessment of Persistence and Motivation

Puzzle Task. The Challenging Puzzle Task was designed to measure young children's achievement goal orientations, similar to the paradigm described in Smiley and Dweck (1994). The puzzle task involves manipulating colored blocks of various shapes and sizes and was selected to be similar to toys and games that children might be familiar with at their schools and homes. Children are shown a card with a design and asked to build a puzzle to match the design on the card, "Build a puzzle that looks like this picture." Children have four minutes to

successfully complete the puzzle pictured on the design card, although they are unaware of the time limit. Experimenters do not provide help or hints to the child during the task but if prompted by the child respond, “You have everything you need” or “Try looking at the picture closer.” There are four design cards ranging from very easy (all children are expected to complete relatively quickly) to very challenging (no children are expected to finish within the allotted time of four minutes). As such, children successfully complete the first puzzle and then are provided a more challenging, second design card. If the child successfully completes the second puzzle, in four minutes or less, a third, even more challenging design card is provided. Likewise, if the child is able to complete the third puzzle, in the allotted time, they are given the most challenging fourth design card. The task is over when the child does not successfully complete a puzzle (either ‘gives up’ or does not complete within four minutes). Thus, some children will only attempt two design cards and others attempt up to four. The last design card the child attempts is recorded as that child’s terminal puzzle. Persistence is assessed for the child’s terminal puzzle as time the child spends attempting to recreate the design card (max = 240 s). The experimenter then asks the child a series of prompts to assess the child’s desire for challenge on the particular puzzle and their interpretation of the puzzle’s difficulty. The experimenter then assists the child in completing the terminal puzzle.

Puppet Interview. Directly following the puzzle task, the experimenter administers a puppet interview to assess the student’s intrinsic value and perceived competence beliefs about the puzzle task. The puppet interview is an eight-item measure adapted from the Puppet Interview Scales of Competence in and Enjoyment of Science (PISCES; Mantzicopoulos, Patrick, & Samarapungavan, 2008), in which children are presented with puppets that “speak” to the child. One puppet says a positive statement (i.e. *“I like doing puzzles like this one.”*) and the

other says a negative statement (i.e. *“I don’t like puzzles like this one.”*). The experimenter then asks the child to identify which puppet thinks the same as them, and directs him or her to point to the matching puppet. Children respond to four dichotomous (positive/negative) statements that capture perceived competence (Puzzles like this one are easy/hard, I know/don’t know how to do puzzles, I can/can’t do puzzles, I’m good/not so good at puzzles) and four dichotomous statements that capture intrinsic task value beliefs (I like/don’t like doing puzzles like this one, I have/don’t have fun doing puzzles, I want/don’t want to know more about puzzles, I feel/don’t feel happy when I am doing puzzles). Prior to assessment of perceived competence and intrinsic value beliefs, children are introduced to the animal puppets (tiger, monkey, giraffe, zebra) as Alex and Taylor (gender-matched to the child) and presented with two ‘test’ statements about recess and pizza to check for understanding and puppet preference. Positive and negative statements are balanced between the puppets, and choice of animals is random. Identification with a positive statement is scored as a one and identification with a negative statement is scored as a zero. Sum scores are then created separately for perceived competence and intrinsic value, ranging from zero (identification with only negative statements) to four (identification with only positive statements).

Electrophysiological Recording

Electroencephalogram (EEG) was collected during task performance of the Go/No-Go task. Recordings were made from 32 sites using a quikCap (Brain Products; Munich, Germany) and actiChamp amplifying system. Data was recorded using Cz as a reference electrode and transformed offline to an average reference. Electrode impedances were kept below 10k Ω and vertical electroculogram (VEOG) was recorded from electrodes placed above (FP1, FP2) and

below (facial passive electrodes) the eyes. EEG activity was digitized online at sampling rate of 250 Hz/channel.

During data cleaning, excessively noisy or high drift channels were removed from data. Next, extraneous movement artifact and non-data EEG segments were removed manually prior to data filtering (bandpass filter 0.1 – 30 Hz). Data were then re-referenced offline to an average of scalp sites (28 electrodes) and run through an algorithm removing artifact below .5 mV or above 500 mV, or exceeding a 500 mV change in voltage between 200 ms intervals. Eye movement and blink artifacts were regressed using an ocular artifact reduction tool in the Brain Vision Analyzer system, set at a 30% threshold. EEG epochs of 1000 ms (with 400 ms pre-response baseline) were extracted for response-locked ERPs for Go and No-Go trials.

Epochs exceeding an EEG voltage threshold of $\pm 150\mu\text{V}$ were considered data artifact and thus, excluded from analysis. Epochs were baseline corrected to the pre-stimulus interval between -400 and -200 ms. Participants with fewer than 6 usable trials for each component were excluded from further analysis (Pontifex, et al., 2010).

The CRN. Peak detect was used to identify the negative most deflection within -100-100 ms of a correct response to account for individual differences in latency. Mean amplitude for the CRN was calculated as 100 ms area surrounding the peak.

The ERN. Peak detect was used to identify the negative most deflection within -100-100 ms of an incorrect response to account for individual differences in latency. Mean amplitude for the ERN was calculated as 100 ms area surrounding the peak.

The Pe component was identified as the peak between 200 and 500 ms post-response for incorrect trials, and the mean activity 200 ms surrounding the peak was extracted.

Statistical Approach

Preliminary descriptive analyses were first run to assess variance for all variables of interest. These analyses revealed that some measures would be best included as categorical variables in our analyses, including the main dependent variable of persistence which was then dichotomized into high (max duration of persistence of 240 s) and low (duration of persistence below 240 s) persistent groups. Next, analyses of the ERP data were conducted to establish the presence of the CRN, ERN, and Pe components using repeated measures ANOVAs. Age was then assessed as a potential covariate in our analyses due to the documented relation between age and EF throughout development (Anderson, 2002).

To address the current research questions, between subjects (high persistent vs. low persistent) differences were assessed in order to garner a better understanding of child characteristics associated with persistent behavior. Chi-square analyses were run to determine whether gender, intrinsic value, or competence were related to child's likelihood to persist. Additionally, univariate ANOVAs were run, controlling for age, assessing differences in EF skills that may be associated with persistent behavior. In these models persistence was entered as a between subjects variable and measures of EF (HTKS) and response monitoring (Go/No-Go performance and ERN and Pe components) were analyzed as continuous outcome variables. We then performed a second round of univariate ANOVAs assessing potential moderators (gender, intrinsic value, and perceived competence) for the relation between persistence and cognition (EF and response monitoring).

Results

Assessing Variance in Behavioral Measures

Descriptive statistics for behavioral measures (HTKS, Go/No Go game, Puzzle task, Intrinsic, Competence) can be found in Table 2. Overall, students performed well on all

behavioral measures. Although students averaged a high score on the HTKS ($Mean=71.73$, $SD=15.10$), a wide range in performance was observed (15-92). Similarly, accuracy on the go/no-go task was well above chance ($Mean=80.49$, $SD=6.37$), however, the percent correct was normally distributed above chance (minimum inclusion criteria: 60; range: 61.33-90.03). As a result, both of these variables were incorporated as a continuous variable in all analyses.

For the puzzle task, all children successfully completed the first puzzle and no children were able to complete the fourth puzzle in under 4 minutes. The terminal puzzle was indicated as puzzle 2 for 15.5% ($N=13$), puzzle 3 for 69% ($N=58$), or puzzle 4 for 15.5% ($N=13$) of children. The majority of students sampled showed high persistent behavior, with only 29 children out of 84 not persisting for the fully-allotted time (4 minutes) during the child's terminal puzzle in the task. Given the distribution of the data, a categorical variable was created to separate children into two groups: high persistent (continued effort on terminal puzzle for 4 minutes) and low persistent (chose to end effort on terminal puzzle before 4 minutes). Additionally, most children showed high intrinsic value ($Mean=2.61$, $SD=1.40$, $Median=3$; $Range=0-4$) and competence ($Mean=2.83$, $SD=1.05$, $Median=3$; $Range=0-4$) for the puzzle task and so, similarly, binary variables were created to represent high (scores of 3 or 4) and low (scores of 0, 1, or 2) intrinsic value and high and low competence. Sample sizes for high and low groups for each variable can be found in Table 3.

Pearson correlations revealed that performance across behavioral measures was related. A greater number of puzzles completed during the puzzle task was related to higher HTKS scores ($r(84)=.342$, $p=.001$), greater accuracy on the Go/No-Go task ($r(64)=.262$, $p=.037$), fewer errors of omission on the Go/No-Go task ($r(64)=-.305$, $p=.014$), and faster reaction times to correct trials on the Go/No-Go task ($r(64)=-.228$, $p=.070$).

Confirming ERP Components

To confirm location and magnitude of the ERN and Pe components, two separate 5x2 repeated measures analysis of variance (ANOVAs) were run with site (Fz, FCz, Cz, CPz, and Pz) as the within subjects factor and response (correct, error) as the between subjects factor for both neural markers. In line with the literature, both the ERN and Pe components were found for the incorrect responses (ERN: $F(1,46)=37.337, p<.001, \eta^2=.448$; Pe: $F(1,46)=12.031, p=.001, \eta^2=.207$), with the ERN showing a more negative value than the CRN, and varied as a function of location on the scalp (ERN: $F(4,184)=61.506, p<.001, \eta^2=.572$; Pe: Site $F(4,184)=4.869, p=.013, \eta^2=.096$). Additionally, there was a statistically significant interaction effect that confirmed that the ERN was maximal at the frontocentral site (FCz) ($F(4, 184)=15.657, p<.001, \eta^2=.254$; see figures 2 and 3) and the Pe was maximally enhanced at the parietal site (Pz) ($F(4, 184)=43.414, p<.001, \eta^2=.486$; see figures 2 and 4) as expected (Gehring, et al., 2012), indicating that it was reasonable to proceed with interpretation of the ERP data.

Age as a Covariate

Age at date of participation, was calculated in number of days since birth and averaged across the two collection sessions. Age was not significantly related to persistence ($p=.155$), intrinsic value ($p=.599$), or competence ($p=.852$) for the challenging puzzle task. However, age was significantly related to most behavioral measures of EF and response monitoring (see Table 4) such that older children had better performance on the HTKS and faster reaction times in the Go/No-Go computerized game. Additionally, age was related to the CRN component ($r(47)=-.406, p<.001$) such that younger children had stronger CRN reactivity only to correct trials. No other relations between age and neural activity were observed (see Table 5). Thus, age was only included as a covariate in analyses including measures of EF and response monitoring.

Persistence and Measures of EF and Response Monitoring

Correlations between performance variables on the Go/No-Go task are presented in Table 4. Within task, accuracy measures were correlated such that children with a higher percent correct (pressing on a Go stimuli and not pressing on a No-Go stimuli) also had fewer incorrect trials, both in terms of errors of commission on No-Go stimuli ($r(64)=-.511, p<.001$) and errors of omission on Go stimuli ($r(64)=-.805, p<.001$). Children on average had faster reaction times on incorrect responses than correct responses ($t(63)=11.726, p<.001$), however reaction time was also correlated between correct and incorrect responses ($r(64)=.652, p<.001$). Moreover, speed was related to accuracy such that children who were faster on correct trials in the Go/No-Go task showed poorer performance such that they made more errors of commission on the No-Go trials ($r(64)=-.505, p<.001$). For descriptive information, see Table 2.

Correlations between behavioral measures of EF can also be found in Table 4. Better scores on the HTKS were related to fewer errors of omission on the Go/No-Go task ($r(64)=-.335, p=.007$) as well as faster reaction times for both correct ($r(64)=-.472, p<.001$) and incorrect trials ($r(64)=-.277, p<.001$).

ERP Associations

Associations between neural components are presented in Table 5. The amplitude of children's ERP responses immediately following the commission of errors (ERN) and correct responses (CRN) was not correlated ($p=.283$). However, the amplitude of the more latent ERP response following an error of commission (Pe) was related to the latter amplitude of the Pe following correct responses ($r(47)=.282, p=.055$). For correct responses, stronger reactivity in the CRN component was related to greater amplitude for the more latent parietal reactivity ($r(47)=-.468, p<.001$). The CRN component was not significantly related to the Pe for incorrect

responses ($p=.169$), but the ERN was related to this Pe at trend level ($r(47)=-.279, p=.058$). The ERN was also related to the Pe observed on correct trials ($r(47)=-.294, p=.045$).

Correlations between ERP and behavioral measures can also be found at the bottom of Table 5. In regards to the relation between behavioral Go/No-Go task and neural reactivity, several correlations were found. Enhanced reactivity in the CRN was related to greater errors of commission on the Go/No-Go task ($r(47)=-.409, p=.004$; responding to the No-Go stimulus). In contrast, a more attenuated CRN was related to slower reaction times ($r(47)=.625, p<.001$) and fewer errors of omission ($r(47)=.278, p=.058$).

Considering children's responses to errors in particular, an enhanced ERN was related to fewer errors of commission ($r(47)=.301, p=.040$) and a larger percent of correct trials ($r(47)=-.279, p=.057$; pressing button on Go stimulus). Additionally, an enhanced Pe component to incorrect trials was related to fewer errors of omission ($r(47)=-.276, p=.060$; not pressing button on Go stimulus) and a greater percent of correct trials ($r(47)=.324, p=.026$). No statistically significant correlations emerged with the Pe following a correct response.

HTKS scores were related to enhanced reactivity in the CRN component on a trend level ($r(47)=-.263, p<.1$) such that children with an enhanced CRN also showed greater behavioral regulation. However, HTKS performance was not related to any other measure of neural activity.

Associations between child characteristics and persistence

Chi-square analyses revealed that persistence was varied as a function of both a child's gender and their self-reported level of intrinsic value. Overall, girls were more likely to show high persistence than boys ($\chi^2(1,84)=4.687, p=.030$) such that only 51.52% of boys (17 out of 33) persisted for the complete duration of the puzzle game, whereas 74.51% (38 out of 51) girls showed high persistence (see Figure 5). Additionally, intrinsic value significantly differed among

high and low persistence groups ($\chi^2(1,84)=6.052, p=.014$) such that students who were high in persistence were more likely to report high intrinsic value for the puzzle task (see Figure 6).

Gender also interacted with intrinsic value ($\chi^2(1,84)=6.052, p=.014$), such that intrinsic value was only significantly associated with boys' performance ($\chi^2(1,33)=3.694, p=.055$). Boys in the high persistence group were more likely to report high intrinsic value than boys in the low persistence group. No differences in persistence as related to intrinsic value were identified for girls (see Figure 7). No statistically significant relation was found between persistence and competency.

Associations between persistence, EF, and response monitoring

HTKS scores did not differ as a function of high and low levels of persistence ($F(1,81)=.118, p=.732$). However, a main effect of persistence was found for percent correct trials in the Go/No-Go game at a trend level ($F(1,63)=3.087, p=.084, n_p^2=.048$) such that children with higher response inhibition scores were more likely to persist fully. This finding reached significance when accounting for the child's report of competency in the model ($F(1,69)=18.897, p=.025, n_p^2=.869$). Thus, children that had higher accuracy on the Go/No-Go task were more likely to be in the high persistence group.

A main effect of persistence was also found for reaction time on correct trials in the Go/No-Go task ($F(1,59)=12.222, p=.004, n_p^2=.481$) when accounting for the variance in child's report of competency. Specifically, children with faster reaction times to Go stimuli were more likely to be in the high persistence group. This interpretation was further supported by a similar main effect of persistence on reaction time to No-Go trials ($F(1,59)=10.718, p=.003, n_p^2=.268$) when competency was accounted for, indicating that children that had faster responses on the Go/No-Go game were more likely to persist in the puzzle task (see Figure 8). No other

statistically significant differences ($p > .1$) between high and low persistent groups were found for performance on the Go/No-Go task or for neural reactivity (ERN and Pe).

Interactions between persistence, child characteristics, and EF

In order to investigate an integrative effect of student motivation and EF on persistent behavior, intrinsic value and perceived competence groups were tested as possible interactions with high and low persistence groups on HTKS performance. A significant interaction emerged between competence and persistence as they related to HTKS score ($F(1,79)=4.548$, $p=.036$, $n_p^2=.054$; see Figure 9). Specifically, the relation between persistence and EF was only significant for children who reported low competence. Students with higher EF as indexed by HTKS score were more likely to persist fully than children with lower EF ($F(1,23)=5.116$, $p=.034$, $n_p^2=.196$). Additionally, the relation between competence and EF was only statistically significant for the children in the high persistence group. In the high persistence group, higher levels of EF were found for children that reported high competence than children that reported lower competence ($F(1,54)=4.271$, $p=.044$, $n_p^2=.076$). No other significant interactions with persistence were found as related to HTKS performance.

Interactions between persistence, child characteristics, and response monitoring

The interactive effects of intrinsic value and perceived competence with high and low persistence groups were also examined on behavioral performance in the Go/No-Go task. An interaction effect between intrinsic value and persistence was found for accuracy on the Go/No-Go game for both Go trials ($F(1,59)=3.984$, $p=.051$, $n_p^2=.063$) and errors of commission students made on No-Go trials ($F(1,59)=5.899$, $p=.018$, $n_p^2=.091$). Overall, children that showed better performance on the Go/No-Go task were more likely to report higher intrinsic value if they showed high persistence on the challenging puzzle (see Figure 10). Follow up analyses revealed

that the relation between persistence and accuracy on Go trials was only significant for the children that reported high intrinsic value ($F(1,40)=6.584, p=.014, n_p^2=.148$). This pattern reached trend level significance for errors of commission ($F(1,40)=3.709, p=.062, n_p^2=.089$). The association between response monitoring and intrinsic value only reached statistical significance for the high persistence group of children ($F(1,44)=8.401, p=.006, n_p^2=.167$). Specifically, children that had lower errors of commission on the Go/No-Go task were more likely to report higher intrinsic value.

Interactions between persistence, child characteristics, and neural components of response monitoring. Before exploring interactions between motivation and neural markers, differences as a function of high/low motivational beliefs were assessed for all ERP components. Enhanced CRN ($F(1,44)=4.221, p=.046, n_p^2=.088$) and ERN ($F(1,44)=4.668, p=.036, n_p^2=.096$) components were found for children who reported high levels of competency (ERN:-9.579, SD=5.103; CRN:-3.710, SD=4.308) as opposed to low levels of competency (ERN:-6.131, SD=3.181; CRN:-.9687, SD=3.814) in the puzzle task. No differences were found for groups based on high/low intrinsic value or for the Pe component for correct or incorrect responses.

Last, interactions between intrinsic value and perceived competence with high and low persistence groups were tested for relation to the CRN, ERN and Pe components. An interaction emerged between gender and persistence for both the ERN ($F(1,42)=3.907, p=.055, n_p^2=.085$) and the Pe to incorrect responses ($F(1,42)=3.133, p=.084, n_p^2=.069$). Specifically, the relation between persistence and neural reactivity was only significant for boys. Boys that had stronger neural reactivity to incorrect trials were more likely to persist fully than boys with more attenuated ERN ($F(1,17)=5.504, p=.034, n_p^2=.282$) and Pe ($F(1,17)=3.344, p=.089, n_p^2=.193$) components (see Figure 11). Additionally, the relation between gender and neural activity was

only significant for the children in the high persistence group. In the high persistence group, boys had stronger ERN ($F(1,31)=4.068, p=.053, n_p^2=.123$) and Pe ($F(1,31)=6.667, p=.015, n_p^2=.187$) components than girls (see Figure 12).

Discussion

The present study assessed the relation between aspects of student cognition, motivation, and persistence in a school-based sample of early elementary students. To our knowledge, this is the first project designed to assess the relation between aspects of school readiness utilizing an interdisciplinary method exploring these relations across measures of brain and behavior.

Specifically, this study aimed to examine interactions between cognitive skill and motivational beliefs that influence persistent behavior during a challenging puzzle task. Results indicate that persistence is related to a child's gender, intrinsic value, and cognitive control capacities.

Overall, children that showed high persistence reported higher intrinsic value and had greater accuracy on the Go/No-Go task. Girls were also more likely to show high persistence than boys.

Further probing suggested that the relation between persistence and intrinsic value was particularly salient for boys, such that boys that showed high persistence were more likely to report high intrinsic value than boys that showed low persistence. The relation between EF, cognitive control skills, and persistence was variable across high and low reports of intrinsic value and perceived competence, such that children with higher cognition as assessed by the HTKS and Go/No-Go task reported higher levels of perceived competence and intrinsic value, respectively, if they demonstrated high persistence.

Gender, Motivation, and Persistence

Findings from the current study indicate that girls are more likely than boys to persist at a new challenging cognitive task when in the presence of an experimenter. At this age, children are

more likely to play with same-gendered peers (Geary, 2010) and thus may also be more comfortable with same-gendered adults. To be noted, all experimenters were young women (18-26 years old) potentially creating an environment that supported social relation for young girls more than young boys. Additionally, the observed gender difference in persistence may be related to gender socialization differences where girls are taught to value hard work and social relatedness and boys are taught to value independence and achievement (Dweck, et al., 1978). If it is the case that girls value their social relation with the experimenter, it is possible that this is why a larger percentage of girls persisted. This finding has particular implications for the acquisition of academic skills in elementary school, as early approaches to learning are associated with higher math and literacy growth. Indeed, some evidence suggests that the gender gap in kindergarten literacy skills can be attributed to girls possessing more positive approaches to learning (e.g. attentiveness and persistence) than boys (Ready, LoGerfo, Burkam, & Lee, 2005). Therefore, focusing on ways in which to encourage more positive approaches to learning in boys may be particularly beneficial for student engagement in early schooling. Interactions between gender and reports of intrinsic value as well as gender and neural components of cognitive control propose further reasoning for the observed gender difference in persistence.

While an overall effect emerged between persistence and intrinsic value, such that children who showed high persistence also reported higher intrinsic value, further probing indicated that this relation was only significant for boys. Because there was no difference in how far boys and girls made it in the puzzle task, it is presumed that the task was equally challenging for all children regardless of gender. This suggests that boys may need to enjoy or hold higher intrinsic value for a task in order to show persistence when faced with challenge. However, our findings also indicate that girls show similar levels of persistence across high and low levels of

intrinsic value. This may signify that promoting intrinsic value in girls is less important for encouraging a positive approach to learning, but perhaps more important for promoting engagement in boys. These findings relate to recent work investigating the gender gap in math careers as a function of high school expectancies and values. High school boys reported higher perceived competence and intrinsic value than girls did despite equivalent prior performance in math. However, neither intrinsic value nor perceived competence was related to girls' career planning in mathematics, signifying that getting girls to 'enjoy' math may not be a particularly effective strategy in decreasing the gender gap in STEM fields (Watt, 2007).

Gender differences in neural activity further support that greater value is needed for boys to persist on challenging tasks. High persistence boys showed enhanced ERN and Pe components than low persistence boys. This difference was not present in the neural activity of girls. Further, when looking within all the children who showed high persistence, boys still had more enhanced ERN and Pe components than girls. This indicates that boys that persist also show greater monitoring of their responses in the Go/No-Go game. Previous research links enhanced ERN and Pe response to a greater salience of an error committed, such that when paradigms have greater contingencies for performance (rewards or punishments), children exhibit larger ERN components (Hajack, 2012). Enhanced ERP amplitudes in the cognitive neuroscience literature is thought to index the value attributed to making an error, or the 'error value.' Therefore, boys with a higher error value, as indexed by larger neural responses, also showed higher persistence during a challenging task, and most likely reported higher intrinsic value. Perhaps boys with higher engagement across tasks recruit additional neural resources during performance of challenging cognitive tasks. Notably, no statistically significant interaction between behavioral markers of EF or response monitoring with gender were found, highlighting that neural measures

provide additional information critical to understanding influences on broad skills such as persistence and the reported interaction between gender and intrinsic value.

Motivation, EF, and Persistence

A significant interaction between children's competence and persistence levels were found for performance on the HTKS. Findings show that children with higher EF scores that demonstrated low persistence also reported lower competence. Additionally, within the children that showed high persistence, high competence was related to higher scores on the HTKS. Combined, these findings shows that children with higher EF skills, as measured by the HTKS, report low competence when they show low persistence and high perceived competence when they demonstrate high persistence. Because progression in the puzzle task was positively associated with higher EF scores, it is possible that children with higher EF are more attentive to their performance and report evaluations of their competence based on the duration of persistence. Whereas previous research has categorized perceived competence as a marker of expectancy (Kim, et al., 2017) in line with Wigfield's expectancy-value theory (2006), in the current study the puppet interview took place following the participant's performance and therefore is more likely a marker of the child's self-performance evaluation. Therefore, it is not surprising that children with higher EF who show persistence report higher competencies, as children with higher self-efficacy also show greater persistence (McTigue & Liew, 2011). Further, due to the correlation between EF, as measured by the HTKS, and progression in the puzzle task, children with higher EF who show persistence are potentially the children who are performing higher, and thus they are more accurately rating their competency.

Additional evidence from neural measures indicate a relation between ERP components and both children's EF and perceived competence, potentially indicating that these constructs

share neural resources. If so, this might help explain the behavioral interaction between competence and HTKS that was found for children's persistence. Specifically, an enhanced CRN component was related to better HTKS performance, highlighting that children with higher EF skills may also have higher cues to attend to the task in order to avoid future errors (Luu, Flaisch, & Tucker, 2000). Additionally, enhanced CRN and ERN components were found for children that reported high levels of competency in the puzzle task. Together, these findings indicate that children with larger error values also show higher EF and perceived competence. The findings presented here support previous work that shows a relation between children's motivational beliefs and response monitoring ERPs, although in differing components (ERN/CRN vs. Pe). This could be due to differences in analytic approaches across the two investigations. The current study created dichotomous variables out of intrinsic and competence variables whereas the previous study (Kim, et al., 2017) assessed the expectancy (competence) and value (intrinsic) of children's puzzle scores as continuous.

The similar relation between brain and behavior for both EF and perceived competence propose that perhaps children with higher approaches to learning recruit response monitoring processes during the engagement of a novel and challenging cognitive task. However, consideration of the gender interaction between intrinsic value and persistence, reported above, hints that brain and behavior relations may differ as a function of gender and motivational construct (intrinsic value vs. perceived competence). More work is needed to disentangle the relation between these constructs related to a child's approach to learning and response monitoring brain activity.

Persistence and Response Monitoring

Children with high levels of persistence also showed greater response monitoring skills as measured by higher accuracy on the Go/No-Go task. This suggests that both measures of EF and cognitive control are related to persistent behavior in early elementary students. Faster reaction times were also related to greater persistence in the puzzle task. However, the relation of reaction times to behavioral performance is somewhat muddled. A negative correlation between reaction time and HTKS score indicates that faster reaction times equate to higher EF skill. However, faster reaction times were also related to greater errors of commission (pressing the button on the No-Go stimulus) which would suggest lower response monitoring skills. These somewhat contradictory correlations are also found in the correlations between brain and behavior markers of response monitoring. Larger CRN reactivity is related to greater errors of commission and faster reaction times on the Go/No-Go tasks. However, larger CRN components were also related to higher EF, as assessed by the HTKS. Due to differences in the development of fine motor skills, we expect that these relations are explained by differences in age. Whereas older children showed higher EF in the sample, perhaps across all children, faster reaction times is related to greater errors in the Go/No-Go task.

An interaction was also found between intrinsic value and persistence for response monitoring skills. For children who reported same levels of liking (high intrinsic value for puzzle task), children with greater response monitoring skills as measured by performance accuracy, showed greater persistence. Additionally, within the children who showed high persistence, greater response monitoring skills were related to high levels of reported intrinsic value. Neural data suggests that greater accuracy on the Go/No-Go is also related to greater error value and conscious processing of performance as indexed by greater ERN and Pe components. The interaction between intrinsic value and response monitoring somewhat mirrors the interaction

between EF and competency such that children with higher cognitive skills (EF or response monitoring) report higher levels of motivational beliefs (perceived competency and intrinsic value, respectively) when they demonstrate high persistence. When considering this finding in concurrence with the gender interaction by intrinsic value interaction on persistence, perhaps the gender differences in the ERN and Pe components is reflective of boys showing higher intrinsic value for the puzzle task. A larger scale study, examining both expectancies and performance evaluations in relation to brain and behavior measures of cognitive functioning would provide further clarity for these findings.

Conclusions & Future Directions

Over the last twenty years, there has been a push towards increasing early access to education and getting children ‘ready’ for school. Federal and state policies and initiatives such as No Child Left Behind, Race to the Top, and the California First Five have all highlighted the importance of preparedness in physical, social emotional, cognitive, and basic knowledge skills (California Childcare Health Program, 2006). Prior to the current study it was unclear how aspects of school readiness relate to a child’s overall approach to learning. Therefore, the current project served as one of the first studies to examine the relation between children’s cognitive skills, motivational beliefs, and persistent behaviors as these skills are emerging in the context of early elementary school.

Despite the novelty of the current project, the unique socioeconomic and university-associated sample limits the generalizability of the findings to a broader population of elementary-aged students. Therefore, future iterations utilizing a broader socioeconomic sample will be required to better understand the relation between aspects of school readiness across a range of school populations. Moreover, further work might assess the relation between these

skills and academic skill acquisition, to determine whether children's approach to learning mediates the relation between cognitive skill and academic achievement, potentially indicating why intervention projects implementing EF training only report short-term gains in academic skill. Additionally, in the current project we assumed that persistence on a challenging puzzle is congruent to persistence on an academically relevant task (i.e. a difficult math problem). Future research might modify the challenging puzzle task to create challenging math and reading tasks that can help elucidate the relevance of the current findings to children's engagement in the classroom.

Overall, the current study provided evidence that children with higher cognitive skills and more positive approaches to learning (as measured by task persistence) report greater motivational beliefs (intrinsic value and perceived competence). Additionally, evidence indicates that intrinsic value had a direct relation with boys' persistent behavior, but not for girls. Whereas, perceived competence related to persistence as a function of individual differences in EF. Differences in both behavioral performance and neural measures found between genders suggest that boys may need to have additional incentives to demonstrate persistence, whereas girls may persist simply in the presence of an adult. Further, these differences can be observed in neural markers of response monitoring during a computerized task. As such, the present study supports that differences in motivational beliefs and approaches to learning can be observed even at the neural level, emphasizing the importance of considering children's performance across measures of brain and behavior to construct a better understanding of mechanisms supporting learning.

Table 1. *Terminology across fields of study.*

Field of Study	Overarching Category of Skills	Construct Name
Developmental Psychology	Self-regulation	Impulse Control
Neuropsychology	Executive Function	Inhibitory Control
Educational Psychology	Engagement	Self-Control
Cognitive Neuroscience	Cognitive Control	Response Inhibition

Adapted from McClelland, Geldhof, Cameron, & Wanless, 2015. Utilizing brain and behavior measures requires methodology from multiple fields of study. Overarching category of skills and particular constructs within that category of skills are considered relatively equivalent across fields and are indicated in field-specific terminology.

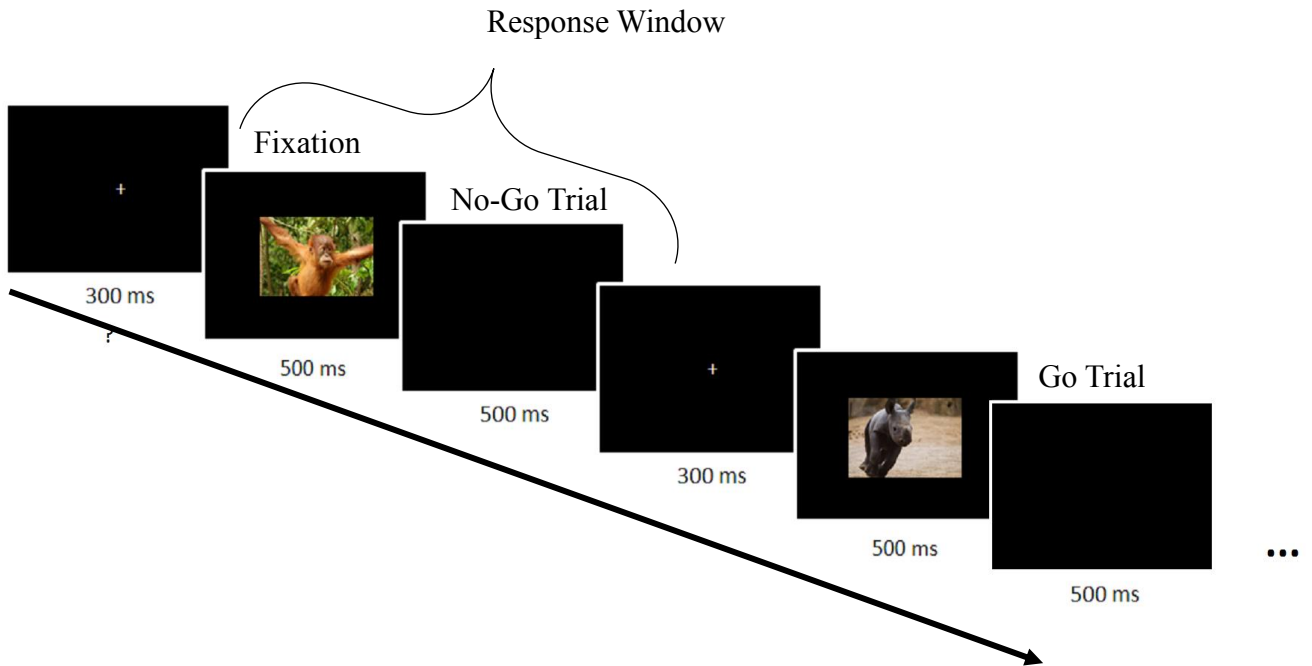


Figure 1. Go/No-Go zoo task. The game consists of 320 trials separated into 8 blocks (75% Go trials, 25% No-Go trials). Stimulus is presented for 500 ms, followed by a 500 ms blank screen, and a 300 ms fixation cross. Response window is 1000 ms.

Table 2. *Performance on Behavioral Measures*

	<i>M(SD)</i>	Median	Range
Persistence (s)	195.36(70.83)	240	16.63-240
Intrinsic Value	2.61(1.40)	3.00	0-4
Competence	2.83(1.05)	3.00	0-4
HTKS	71.73(15.10)	76.00	15-92
Go/No Go Accuracy			
% Correct	80.49(6.37)	82.20	61.33-90.03
% Incorrect	11.02(3.80)	10.69	3.32-19.58
% Errors of Omission	8.48(5.50)	7.23	2.42-31.42
Go/No Go Reaction Time			
Correct Trials (ms)	503.14(75.66)	497.90	229.67-640.28
Incorrect Trials (ms)	417.44(60.60)	405.38	211.39-548.07

Table 3. *Group descriptives for dichotomized variables.*

	Low		High	
	N	<i>M</i> (<i>SD</i>)	N	<i>M</i> (<i>SD</i>)
Persistence	29	110.68(59.42)	55	240(0)
Intrinsic Value	34	1.11(0.84)	50	3.62(0.49)
Competence	24	1.46(0.78)	60	3.38(0.49)

Note: For persistence, cut score was 240 s for placement in high (240 s) vs. low (<240 s) group. For intrinsic value and perceived competence, children with scores of 0, 1, or 2 were placed in low group and children with scores of 3 or 4 were assigned to the high group.

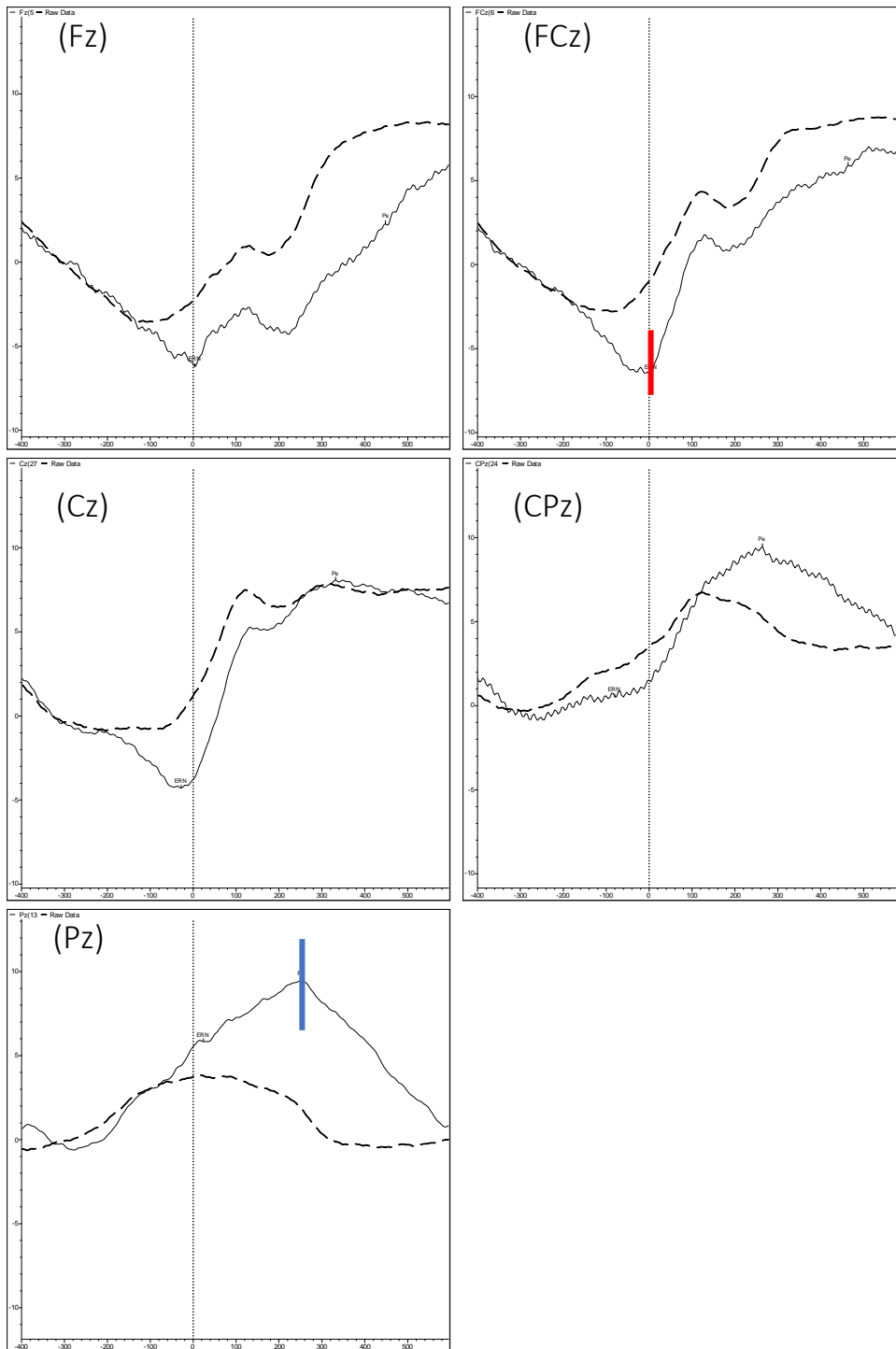


Figure 2. Response-locked ERPs from midline sites. ERN component at FCz. Pe component at Pz. Dotted line is correct response. Solid line is incorrect response. ERN maximal peak is highlighted in red. Pe maximal peak is highlighted in blue.

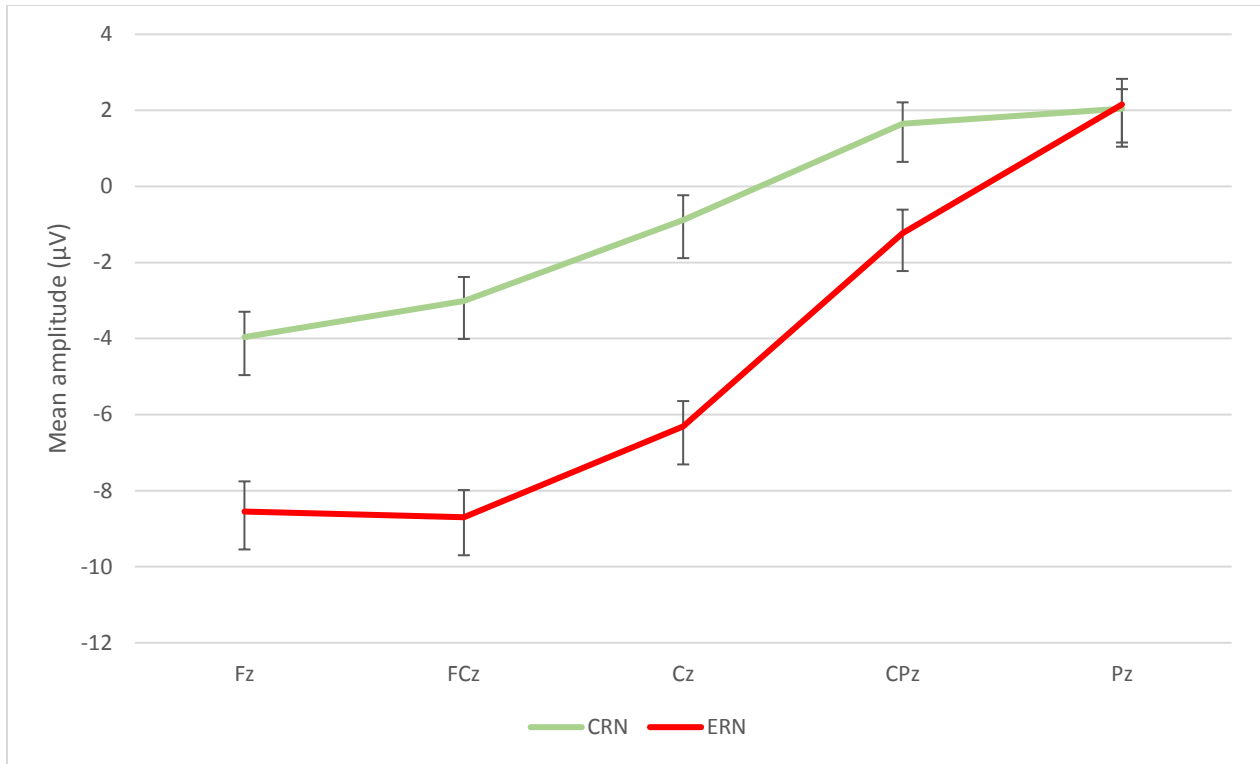


Figure 3. ERN component amplitude: Site by response.

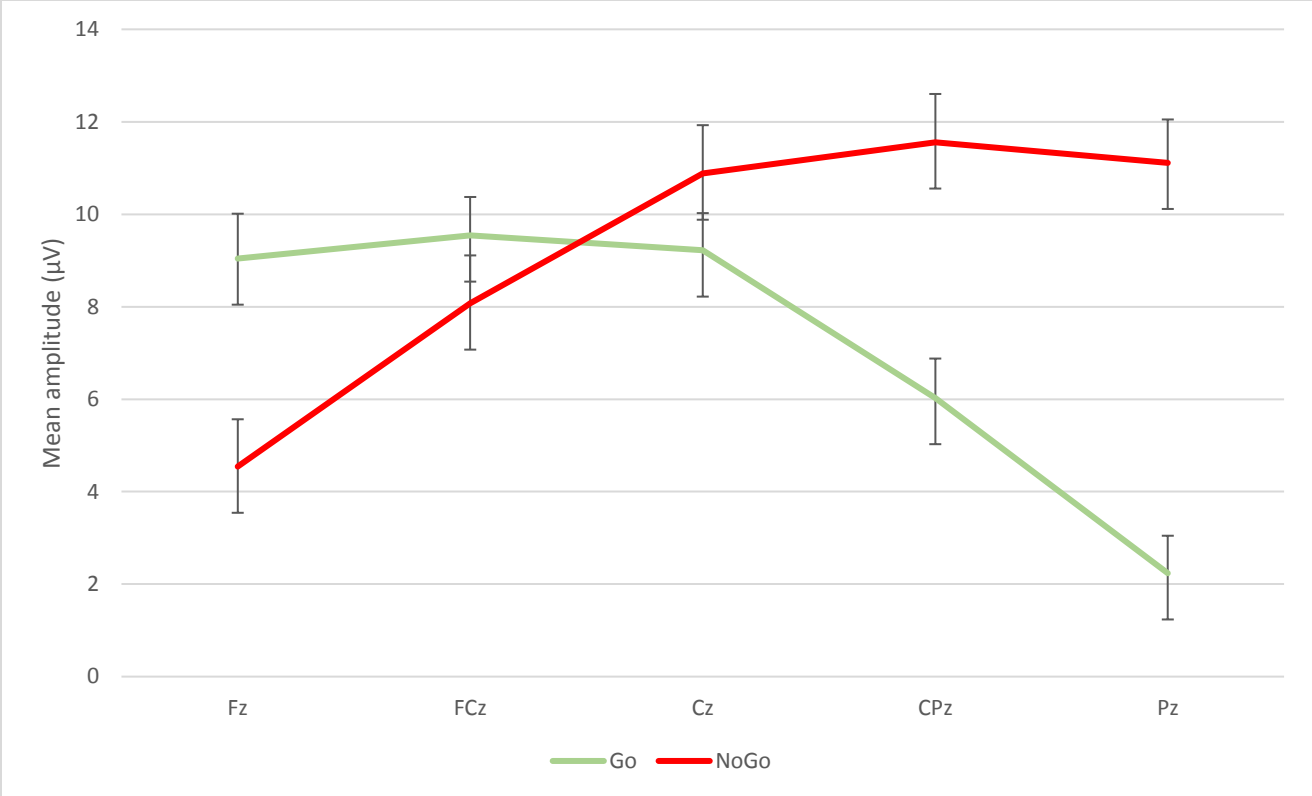


Figure 4. Pe component amplitude: Site by trial.

Table 4. *Correlations between age and behavioral measures of EF.*

N=84	Age	HTKS	%Correct	%Incorrect	%EOM	Correct RT	Incorrect RT
Age	-	.598***	.184	.148	-.316*	-.606***	-.439***
HTKS		-	.252	.063	-.335**	-.472***	-.277***
Go/No-Go (N=64)							
%Correct			-	-.511***	-.805***	.114	.041
%Incorrect				-	-.099	-.505***	-.200
%EOM					-	.217+	.091
Correct RT						-	.652***
Incorrect RT							-

Note: + $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5. *Correlations between neural measures of EF and behavioral measures of EF.*

N=47	Pe			
	CRN	ERN	Correct	Incorrect
CRN	-	.160	-.468***	-.204
ERN		-	-.294*	-.279+
Correct Pe			-	.282*
Incorrect Pe				-
Age	-.406***	-.099	-.039	-.006
HTKS	-.243+	-.026	-.125	.013
Go/No-Go				
%Correct	-.008	-.279+	.031	.324*
%Incorrect	-.409**	.301*	.145	-.129
%EOM	.278+	.114	-.130	-.276+
Correct RT	.625***	.048	-.100	.113
Incorrect RT	.244+	.214	-.014	.073

Note: + $p < .1$, * $p < .05$, ** $p < .01$, *** $p < .001$.

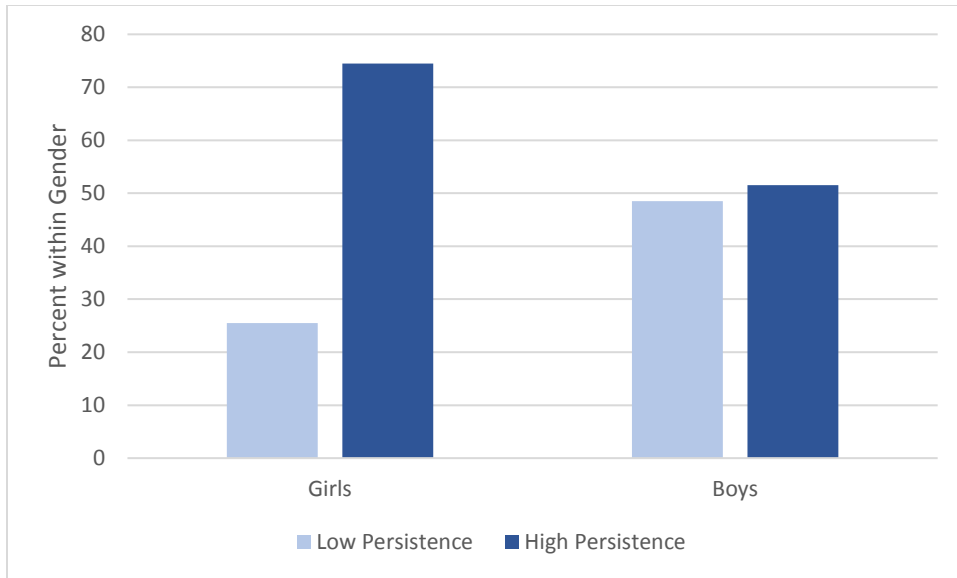


Figure 5. Persistence by gender. High persistence (240 s) vs. low persistence (<240 s) on the puzzle task for boys (N=33) and girls (N=51).

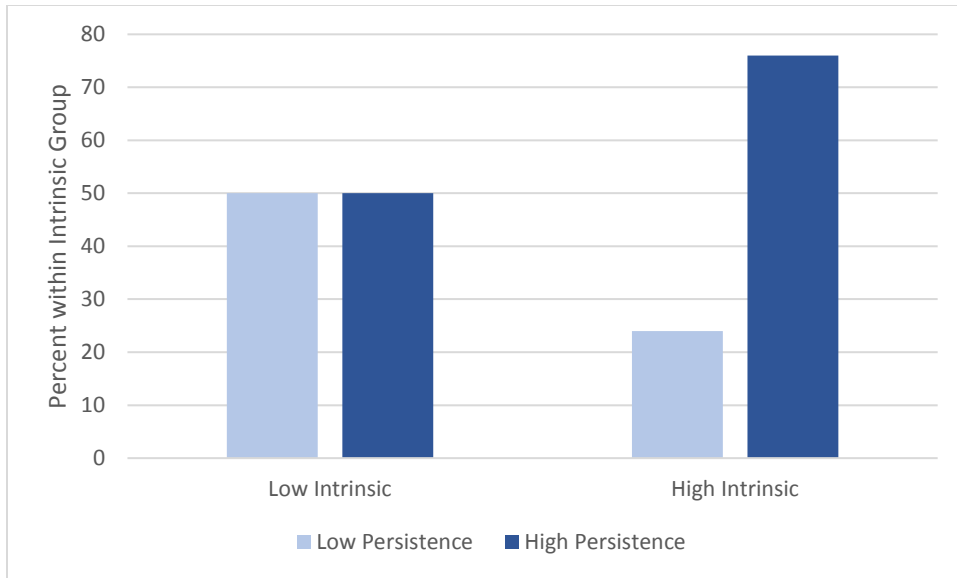


Figure 6. Persistence by intrinsic value. Level of persistence on the puzzle task as indicated for high vs. low for children who reported low intrinsic (N=34) and high intrinsic (N=50) value in the puppet interview.

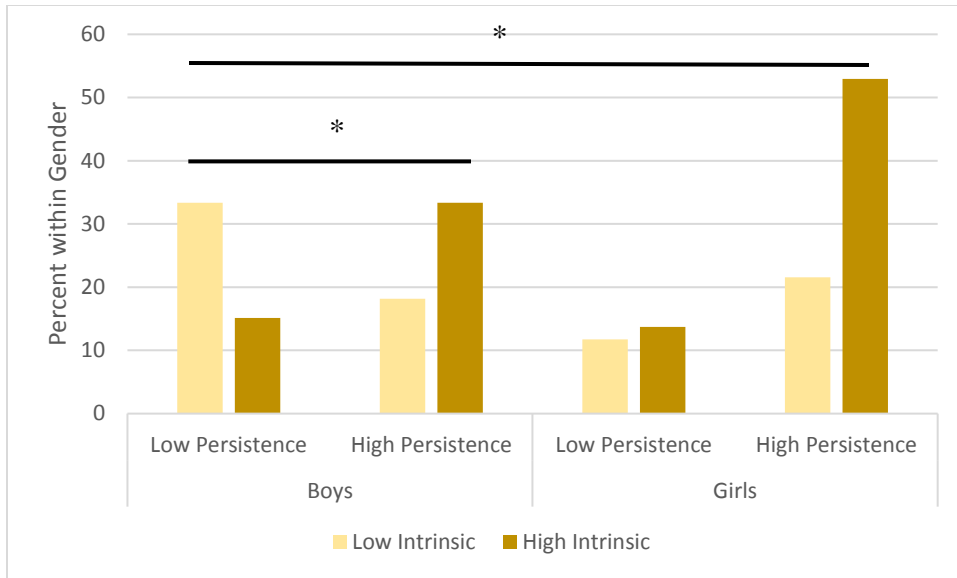


Figure 7. Persistence by intrinsic value by gender. Level of persistence on the puzzle task for children who reported low intrinsic (Boys: N=17, Girls: N=17) and high intrinsic (Boys: N=16, Girls: N=34) value in the puppet interview. The relation between persistence and intrinsic value is moderated by gender, such that proportion of children with high vs. low intrinsic value is only statistically differential across high and low persistence levels in boys.

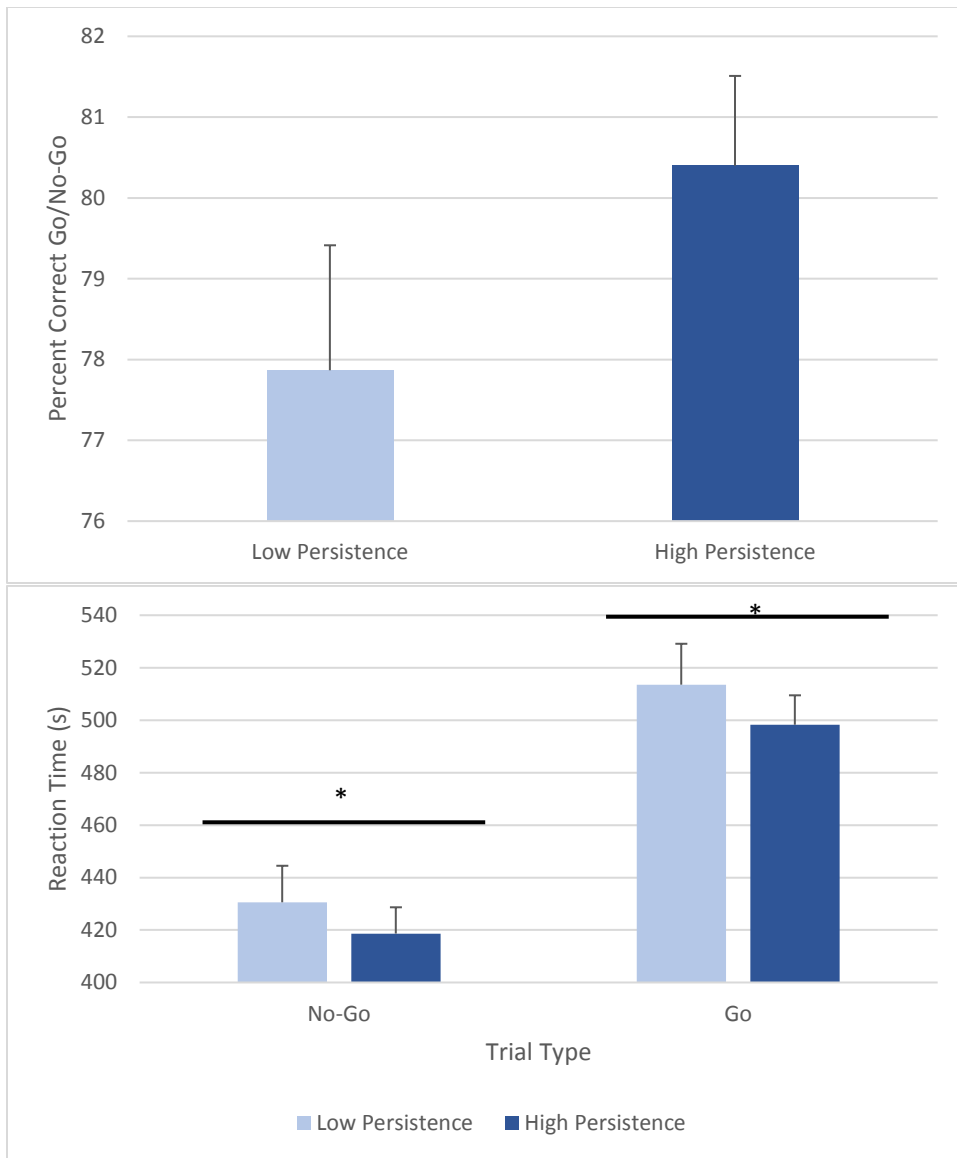


Figure 8. Response inhibition skills by persistence. Performance on the Go/No-Go task for children with low persistent (N=19) and high persistent (N=45) performance on the puzzle task.

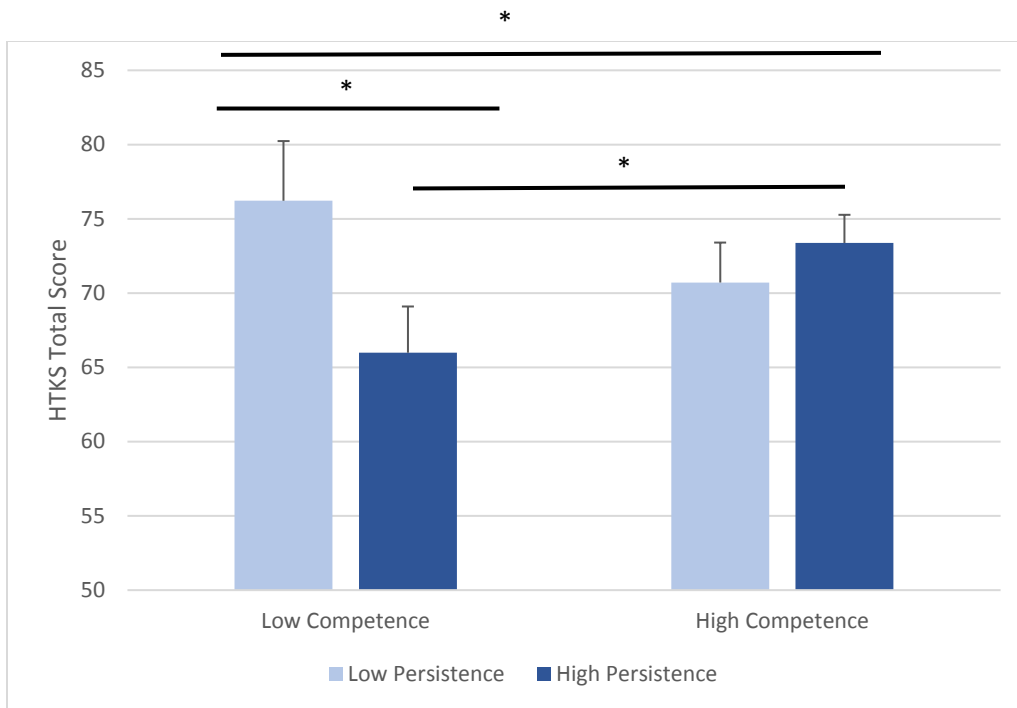


Figure 9. Interaction between persistence and competence on EF. Performance on the HTKS task for children with low persistent (low competence: N=9, high competence: N=20) and high persistent (low competence: N=15, high competence: N=40) performance on the puzzle task. Within children that reported low competence, children with low persistence had higher EF than children with high persistence. Within high persistence group, children that reported high competence had higher EF than children that reported low competence.

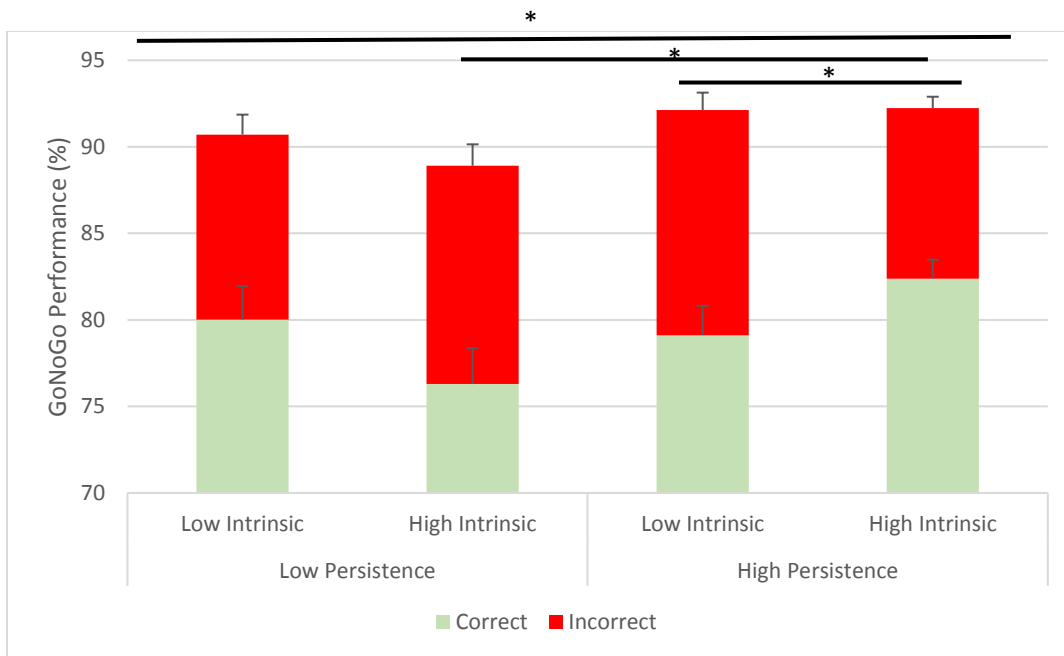


Figure 10. Interaction between persistence and intrinsic value on response inhibition. Go/No-Go performance by level of self-reported intrinsic value and high (low intrinsic: N=13, high intrinsic: N=32) and low (low intrinsic: N=10, high intrinsic: N=9) persistence on the puzzle task. Within children that reported high intrinsic value, children that showed high persistence had greater response monitoring skills than children that showed low persistence. Within children that showed high persistence, children that reported high intrinsic value had higher response monitoring skills than children that reported low intrinsic value.

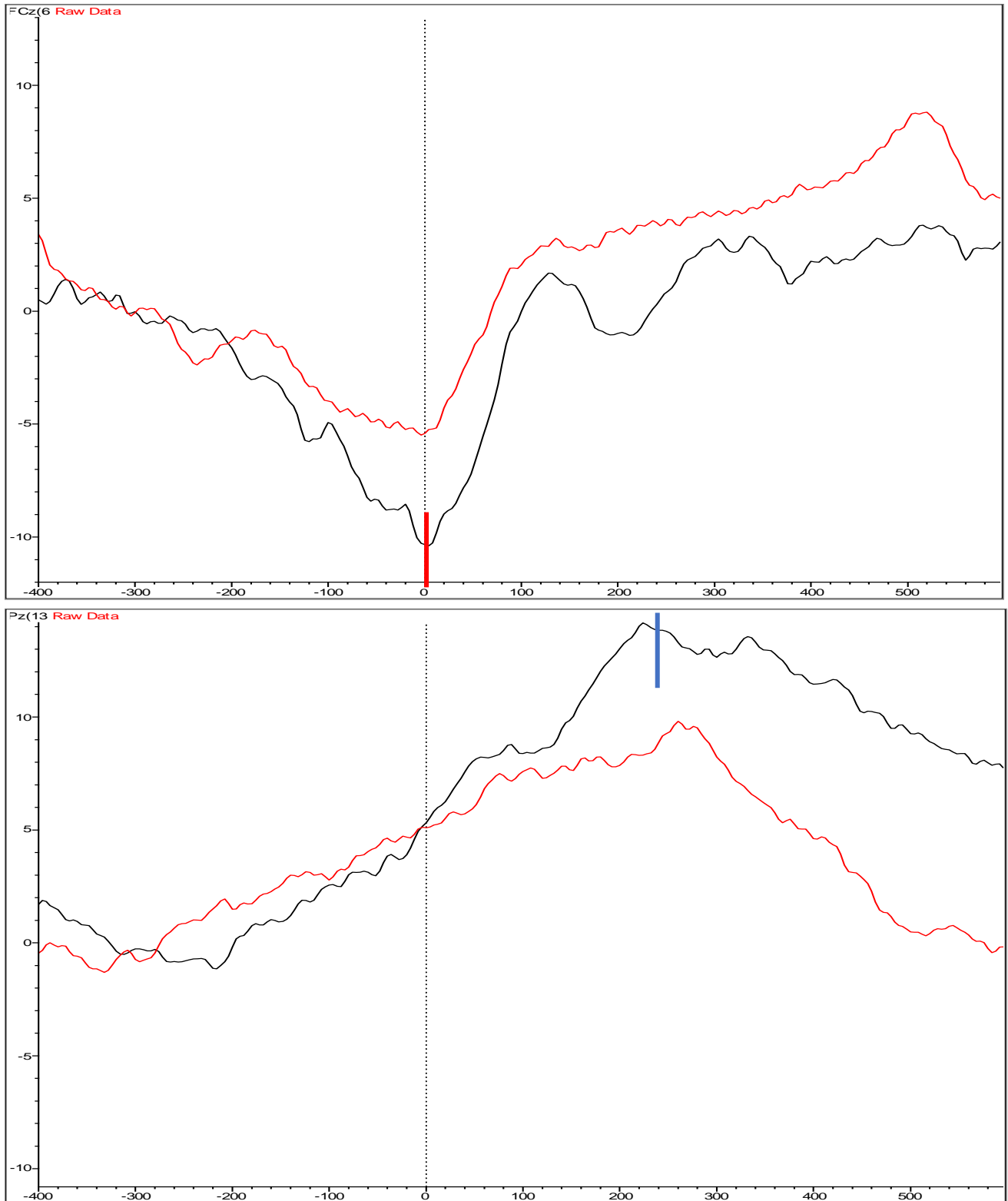


Figure 11. ERN and Pe components in boys by persistence. High persistence is black (N=9). Low persistence is red (N=8). ERN is marked with red. Pe is marked with blue.

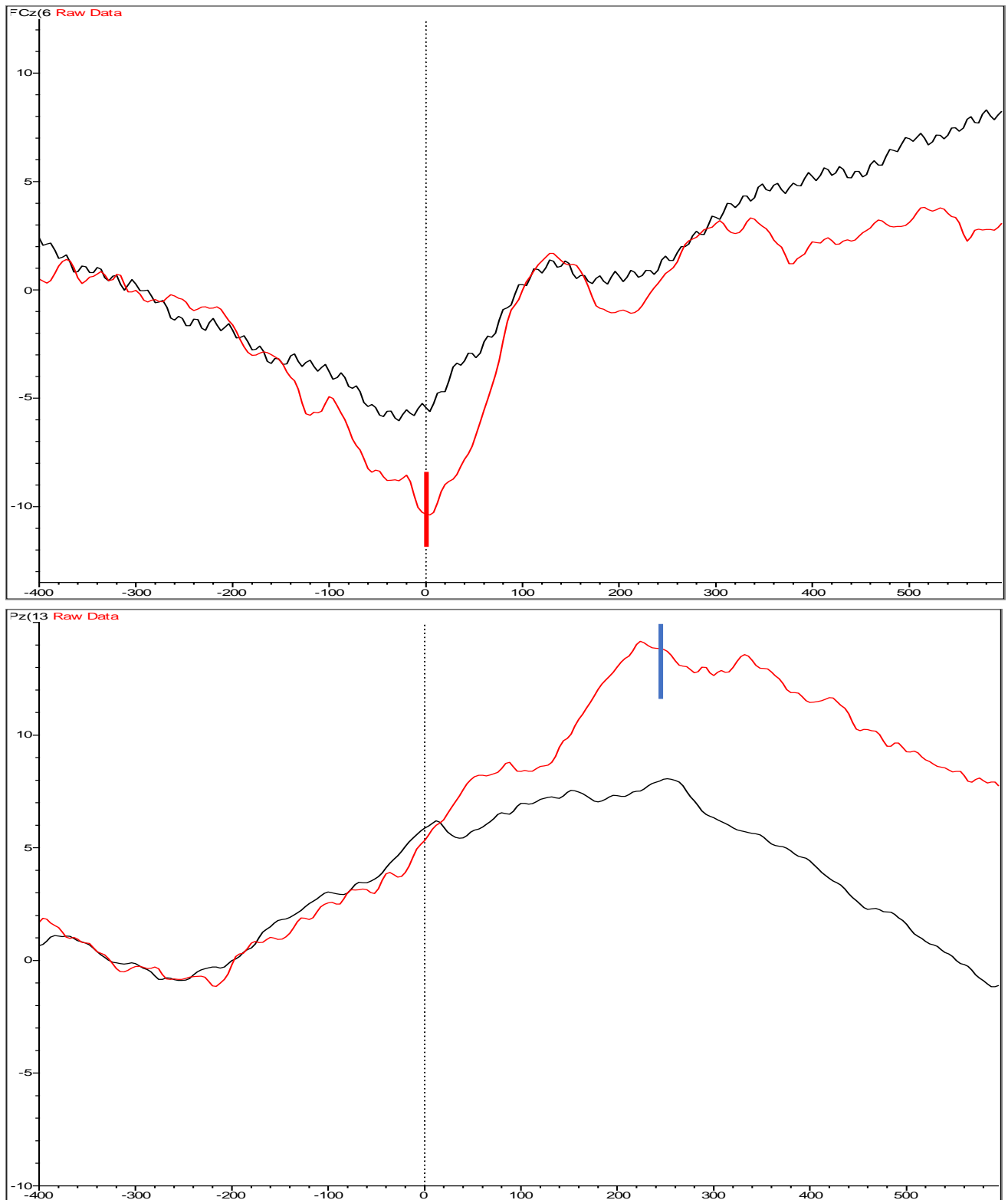


Figure 12. ERN and Pe components for high persistent group by gender. Girls are black line (N=23). Boys are red line (N=9). ERN is marked with red. Pe is marked with blue.

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