The Development of Task Switching in Adolescence and Relationships with Externalizing Symptoms

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Dedication

This dissertation is dedicated to my family and friends for their unconditional love, patience, and support throughout this endeavor.

Abstract

Cognitive flexibility facilitates the ability to quickly change behavior to adjust to changing environmental contingencies by shifting attention away from one task and attending to another. This ability may be one of a number of executive functions that improves through childhood and into adulthood. This study was conducted to examine the development of task switching during adolescence. Specifically, the development of two cognitive processes, attention switching and processing speed, that may underlie task switching ability were examined within a single task. Additionally, the degree to which self-reported externalizing behavior impacts these aspects of task switching ability was investigated. Individuals (N = 177) ages 9 to 23 participated in the study. The results showed that the different cognitive components that underlie task switching ability develop at different rates. Attention switching ability appears to be mature by early adolescence; however, the ability to efficiently activate the upcoming task set, which is likely dependent on processing speed, continues to increase until mid-adolescence. There was limited evidence that externalizing behavior in a non-clinical sample impacts attention switching performance. Externalizing behavior does not appear to significantly influence processing speed. These data clarify the nature of task switching development in adolescence by revealing how age-related changes in two cognitive components that underlie task switching ability contribute to cognitive flexibility.

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Introduction

The ability to rapidly adjust behavior according to changes in the environment depends on intact cognitive flexibility, an aspect of cognitive control that improves during childhood (e.g. Davidson, Amso, Anderson, & Diamond, 2006; Zelazo, Craik, & Booth, 2004). Cognitive flexibility is essential in everyday activities when multiple actions are required to accomplish a goal or when multi-tasking. For example, cognitive flexibility is necessary for a mother who is making dinner while helping her child with his homework or when an adolescent sends a text message while completing her math homework. It is necessary under a variety of circumstances that occur regularly for children and adolescents, such as managing changes in academic demands, driving, playing sports, and coping flexibly with changing social contexts. Task switching paradigms measure cognitive flexibility in that they require a shift in behavior depending on the current goal of the task as indicated by a cue. For example, one type of task switching paradigm involves switching between deciding whether a letter is a vowel or consonant and whether a number is odd or even (e.g. letter, letter, number, number, letter, letter, etc.; Rogers & Monsell, 1995). Thus, task switching requires shifting between task sets. The term "task set" has been defined as the active representation of a task goal and task parameters (Vandierendonck, Christiaens, & Liefooghe, 2008). In task switching paradigms, each task set is cued by a stimulus, which informs individuals of, and allows them to prepare for, the nature of the appropriate response. The cue indicates whether the appropriate response requires repetition of the same task or a switch in task.

A distinction has been made between different types of task set switches (Rushworth, Passingham, & Nobre, 2005). A task set switch that requires participants to switch between different motor responses has been termed "intentional set switching" and a task set switch that requires a switch between different stimuli has been termed "attentional set switching." For example, switching from ironing a shirt to folding it would require a shift in intention as it requires a shift in motor response. A change in attentional set would be necessary to switch between evaluating the color of a painting to appreciating its texture. This distinction illustrates that task switching may require increased attention to different types of stimuli or to different types of actions depending on the nature of the task switching paradigm (Rushworth et al., 2005).

Task switching has been measured by many different types of paradigms, which may measure distinct cognitive processes (Ravizza & Carter, 2008). For example, some paradigms measure perceptual switching by requiring participants to shift between identifying one of several stimulus attributes (e.g. identify the color or shape of an object). In this example, both shapes and colors are presented simultaneously, so task switching requires participants to shift visuospatial attention away from one attribute and selectively attend to the other. Similarly, in object switching paradigms, the relevant stimulus is switched requiring a shift in attention away from one stimulus category and switch in attention to another (e.g. responding to a letter versus responding to a number). There are also more complex task switching paradigms. Some task switching paradigms measure rule switching by requiring a shift in stimulus-response mapping (e.g. press right button if the stimulus is a shape, press the left button if the stimulus is a letter). Tasks measuring rule switching may contain univalent rules (stimuli associated with fixed responses) or bivalent rules (stimuli associated with different responses depending on the cue). Additionally, some paradigms measure multiple types of switching. For example, one paradigm measures perceptual and rule switching by requiring participants to identify the color or shape of an object and then execute the correct stimulus-response rule for that color or shape (Hayes, Davidson, Keele, & Rafal, 1998). Another task switching paradigm requires participants to respond to two different task rules requiring a right- or left-hand response and additionally manipulates the compatibility of the stimulus-response mapping (compatible = right-hand response when stimulus is on the right half of the screen; incompatible = left-hand response when the stimulus is on the right half of the screen) (Crone, Bunge, van der Molen, & Ridderinkhof, 2006a).

Thus, there are many possible skills that contribute to one's ability to behave flexibly. Whether these skills are recruited will depend on the context. Task switching paradigms broadly measure the ability to rapidly respond to changing behavioral goals, but they vary in the extent to which they recruit different cognitive components. For example, tasks requiring rule switching, especially those with bivalent rules, may have a higher working memory demand than tasks measuring perceptual switching. Tasks involving stimulus-response incompatibility may require more conflict resolution and inhibitory control than tasks that do not manipulate compatibility. Despite these distinctions across tasks, there are cognitive processes that are common to task switching paradigms, including sustained visual attention, response selection, and attention switching, defined as the ability to disengage from attending to a previously relevant stimulus or attribute and switch attention to a different stimulus or attribute.

The task switching paradigm used in this study (described in more detail below) can be categorized as an object switching paradigm and, in contrast to more complicated task switching paradigms, isolates the attention switching component of task switching and requires participants to switch between attentional or stimulus sets. The task additionally manipulates the effect of advance preparation on task switching, which allows for the examination of processing speed and how it impacts performance. Cools, Barker, Sahakian, & Robbins (2003) found this paradigm to be dopamine-modulated, and similar paradigms have been shown to be dependent on the dorsolateral fronto-parieto-striatal system (Cools, Barker, Sahakian, & Robbins, 2001; Hayes et al., 1998; Sohn, Ursu, Anderson, Stenger, & Carter, 2000).

Task switching produces a decrement in performance relative to non-switching (repeating the same task) as evidenced by increases in reaction time and errors (Rogers & Monsell, 1995). This decrement is referred to as a switch cost. The switch cost is considered to be a primary measure of task switching ability and is calculated by subtracting performance variables on non-switch trials (trials where the task is repeated) from performance on switch trials (trials that require a switch in task) within a block of trials. It has been suggested that switch costs reflect the increased cognitive control processes required to switch tasks compared to repeating the same task (Meiran, 1996; Rogers & Monsell, 1995). Changing tasks is thought to activate the need for ‘task-set reconfiguration,’ which may involve shifting attention between stimulus attributes, recalling or activating goal states (what to do) and associated response rules (how to do it), and inhibiting the previous task requirements (Monsell, 2003). Studies have shown that switch costs can be reduced with practice, both over the course of several blocks within one session (Koch, 2005; Meiran, 1996) and over multiple sessions (Cepeda et al., 2001; Sohn & Anderson, 2001).

Effect of advance preparation on task switching

The ability to prepare for a switch has been considered an important factor in task switching as it is assumed that task-set reconfiguration must be initiated before successful task execution can begin (Meiran & Marciano, 2002). It has been consistently demonstrated that switch costs can be reduced with increased preparation time, allowing for the initiation of task-set reconfiguration prior to the stimulus onset (e.g. De Jong, 2000; Goschke, 2000; Meiran, 1996; Rogers & Monsell, 1995). Cued task switching paradigms manipulate the duration of the interval between the cue and the stimulus onset, while holding constant the interval from one stimulus presentation to the next, to allow for the examination of the effect of preparation independent of remoteness from the previous trial. Task switches that are signaled by long cue-to-stimulus (CSI) preparatory intervals should be easier than those that are signaled by short preparatory intervals due to the increased amount of time available to prepare. Providing time to prepare for a task switch reduces switch costs in adults (e.g. Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995) and to an even greater extent in children and older adults (Cepeda, Kramer, & de Sather, 2001). Additionally, it has been shown that task switching performance between patients with Parkinson's disease (a disorder that is characterized by deficits in cognitive flexibility) and controls is not significantly different under long CSI conditions, whereas switch costs are increased for patients relative to controls under short CSI conditions (Cools et al., 2003). Therefore, short CSI conditions likely require more efficient or effortful cognitive processing to successfully activate the upcoming task set. Thus, task designs that vary the CSI between trials allow for investigation of the efficiency of activating the upcoming task set.

It seems likely that the efficiency of activating the current task set would be dependent on processing speed and that with increases in processing speed, the current task set could be activated more quickly, thereby reducing switch costs. A short CSI places greater demands on processing speed relative to a long CSI as successful performance on short CSI trials requires faster cognitive processing than long CSI trials. Comparing task switching performance between short and long CSI conditions provides an opportunity to not only to examine the ability to switch tasks, but also how demands for increased processing speed impact task switching performance. Thus, variables that can be measured in cued task switching paradigms include switch costs, which reflect attention switching, and how changes in the preparatory interval, which measures processing speed, impact performance as assessed by error rates and reaction time (see Table 1). The interaction of attention switching and processing speed can be examined by comparing switch costs during short and long preparatory intervals. In theory, the most challenging condition should be the one in which switching is required with a short preparatory interval.

Neural Activation During Task Switching

Based on data obtained from functional magnetic resonance imaging (fMRI) studies, task switching is thought to rely on a network of brain regions including the ventrolateral and dorsolateral prefrontal cortices, pre-supplementary and supplementary motor areas (pre-SMA and SMA), superior and inferior parietal cortices, and basal ganglia (Brass & von Cramon, 2002; Braver, Reynolds, & Donaldson, 2003; Bunge, 2004; Cools, Ivry, & D'Espostio, 2006; Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006b; Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Gruber, Karch, Schlueter, Falkai, & Goschke, 2006; Luks, Simpson, Feiwell, & Miller, 2002; Ravizza & Carter, 2008; Rushworth, Hadland, Paus, & Sipla, 2002; Wager, Jonides, & Reading, 2004; Woodward, Ruff, & Ngan, 2006). A dissociation has been demonstrated in terms of how these regions are activated during task switching performance. The VLPFC and DLPFC are involved in the ability to activate and maintain task set while the pre-SMA/SMA and caudate nucleus are involved in the ability to switch between task sets (Brass & von Cramon, 2002; Crone, Wendleken, Donohue, & Bunge, 2006c; Rushworth et al., 2002). The parietal cortex is thought to be involved in switching and providing the stimulus-response associations required to execute a task (Crone et al., 2006c; Brass & von Cramon, 2004).

Neural activity in a network of frontal and parietal brain regions has been associated with advance preparation, including the inferior frontal junction, DLPFC, ACC, posterior parietal cortex, and intraparietal sulcus (Brass & von Cramon, 2002, 2004; Gruber et al., 2006; Luks, et al., 2002; Ruge et al., 2005). These brain regions have been shown to be activated when the task was switched or repeated suggesting that the activation associated with advance preparation in these regions may not reflect a switch-specific preparation process, but reflects activity associated with activating the upcoming task set regardless of whether it involves a task switch or repeat. These findings lend further support for the role of the DLPFC in activating appropriate task goals and suggest that the ACC is involved in monitoring the preparatory allocation of attention for conflict (Luks et al., 2002).

There is some evidence in the neuroimaging literature to support the notion that different cognitive processes underlie different forms of task switching. For example, Ravizza and Carter (2008) found that the DLPFC was engaged during rule switching and that the right superior parietal cortex was activated during perceptual switching. This study did not find regions that were active during both types of switching. However, Wager et al. (2004) conducted a meta-analysis and found modest dissociations in neural activity during different types of task switching and instead found common regions activated during object and perceptual switching, including the medial prefrontal, superior and inferior parietal, medial parietal, and premotor cortices. The inconsistencies across studies may be due to the wide range of task designs used to measure task switching.

The same brain regions that subserve task switching ability in adults are also active in children and adolescents during task switching, although adults engage these areas differently than children and adolescents (Crone et al., 2006b). Using a complex paradigm that examined task switching behavior under different instructional conditions, Crone et al. (2006b) reported that children and adolescents engaged the VLPFC more during switch versus non-switch trials, whereas adults generated more activity in the VLPFC during bivalent rules (stimuli associated with different responses depending on the cue) than univalent rules (stimuli associated with fixed responses) regardless of whether the rules were repeated or switched. Additionally, children generated more activity during switch trials associated with a univalent relative to a bivalent rule in the VLPFC and additionally recruited the pre-SMA/SMA to activate and maintain the upcoming task set (Crone et al., 2006b). These findings are difficult to interpret given the complexity of Crone's manipulation. It is not completely clear which processes are distinctly associated with each neural region in adults versus children. However, this study does reinforce the notion that task switching, and by extension cognitive flexibility, can be construed as a complex executive function that relies on contributions from various regions of the prefrontal cortex.

Using a less complicated, visuospatial task switching paradigm with only male participants, Rubia et al. (2006) reported that adults generated greater neural activity during task switching than adolescents in brain regions that also showed linear positive correlations between task switching-related activity and age, including the right inferior prefrontal and parietal cortices, ACC, and putamen. Age-related increases in activation in the parietal lobe and putamen remained significant after covarying for performance suggesting that maturation of these brain regions during adolescence is associated with an increased capacity for task switching (Rubia et al., 2006). Using the same task with adolescents and adults ages 13 to 38, Christakou et al. (2009) found age-related increases in activation during task switching in bilateral inferior prefrontal cortex, DLPFC, ACC, premotor and inferior parietal regions, thalamus, and caudate and age-related decreases in activity in the temporal and parahippocampal regions, which they interpreted as reflecting progressive task-specific functional specialization.

Using a perceptual switching paradigm, Morton, Bosma, & Ansari (2009) found that young adults generated switch-related activity in the left superior parietal cortex and the right thalamus whereas adolescents ages 11-13 generated switch-related activity in the right superior frontal sulcus (i.e. pre-SMA/SMA). The authors interpreted this finding to suggest that perceptual switching processes supported by the parietal lobe function less efficiently in adolescents and that adolescents compensate by utilizing other processes to a greater degree than adults, including working memory and planning of goal-directed movement, which are supported by the pre-SMA/SMA (Morton et al., 2009).

It is difficult to interpret the findings across developmental neuroimaging studies of task switching because the studies summarized above measured different types of task switching, which likely rely on different cognitive subcomponents; however, it would be expected that these tasks are each subserved to some extent by attention switching and processing speed, in addition to other cognitive processes. The age-related differences in patterns of activation during task switching likely reflect maturation of the neural networks that subserve the cognitive mechanisms that comprise task switching. The existing literature suggests that the VLPFC and DLPFC are involved in the ability to activate and maintain task set, the pre-SMA/SMA, parietal cortex, and caudate nucleus underlie attention switching, and the white matter tracts that connect the frontoparietal and frontostriatal networks support efficient processing speed.

Behavioral Studies of Task Switching Development

To date, there are only a handful of developmental studies of task switching. A number of studies suggest that task switching reaches adult levels of performance by age 12 as measured by error and reaction time switch costs (Cepeda et al., 2001; Crone, Ridderinkhof, Worm, Somsen, & van der Molen, 2004; Crone et al., 2006a; Crone et al., 2006b; Morton et al., 2009), but there is some evidence that switch costs continue to decrease during adolescence (Davidson et al., 2006), reaching adult levels of performance by age 15 (Huizinga, Dolan, & van der Molen, 2006) or slightly later at ages 16-17 (Reimers & Maylor, 2005; Rubia et al., 2006). Additionally, there is variability between studies regarding age-related differences in reaction time and error variables with some studies reporting that children and adolescents either make more errors or have greater error switch costs than adults, but report no age-related differences in reaction time (Davidson et al., 2006; Morton et al., 2009; Rubia et al., 2006) and other studies reporting more dramatic age-related differences in reaction time variables compared to error variables (Crone et al., 2006a; Reimers et al., 2005). Further, Crone et al. (2004) reported that age-related differences in reaction time and error variables have similar developmental trajectories, while Cepeda et al. (2001) found more protracted developmental trajectories for reaction time relative to error variables. Gender differences have not often been reported in developmental task switching studies; however, Reimers & Maylor (2005) found that males demonstrated higher accuracy rates than females.

These discrepancies likely reflect methodological differences in the task switching paradigms used in these studies and it is difficult to identify commonalities among the tasks that yield the earliest or latest maturation. For example, in addition to measuring task switching, many of the paradigms used in these studies also measured other cognitive processes, including working memory, rule learning, and interference suppression to varying degrees, which complicates interpreting results across studies.

Thus, it is important to consider methodological differences when comparing results between studies.

There are additional factors that have complicated interpretation of findings across developmental task switching studies. Several of the developmental task switching studies failed to adequately sample the entire adolescent age range. Several studies did not include participants older than age 12 or 13 (Crone et al., 2006a; Davidson et al., 2006), and others combined participants ranging from early to late adolescence into one group (Cepeda et al., 2001; Crone et al., 2006b). The studies that did include participants ranging from late childhood to early adulthood have limitations, because they either selected single age groups to represent different stages of adolescence (i.e. 11-, 15-, and 21-year-olds) (Huizinga et al., 2006), only reported on error switch costs (Crone et al., 2004), or collected data in an uncontrolled fashion (i.e. internet-based study) (Reimers & Maylor, 2005). Therefore, although the majority of studies suggest that task switching reaches adult levels of maturity by age 12, this conclusion should be interpreted with caution, as there is the possibility that further development occurs later in adolescence, perhaps between ages 15-17 (Huizinga et al., 2006; Reimers & Maylor, 2005; Rubia et al., 2006); however, given the limitations mentioned above, this possibility requires further investigation.

To date, only one study has examined the contribution of advance preparation on the development of task switching. Cepeda et al. (2001) found that additional time to prepare led to a significant reduction in switch costs that was greater for children through age 12 than young adults, leading to the suggestion that age-related differences in switch costs can be at least partially explained by a decreased ability to prepare for a task switch in children. However, the task used by Cepeda et al. (2001) additionally manipulated response-stimulus compatibility, so it is unclear the effect that incompatibility may have had on the previously discussed findings.

To summarize, issues related to the development of task switching that have yet to be sufficiently studied include 1) the development of task switching independent of other cognitive processes, such as working memory, rule learning, and interference suppression, 2) the development of task switching across the entire span of adolescence, and 3) how different components of task switching develop across the entire range of adolescence and how does the development of each contribute to overall task switching development. In addition to these areas that require further investigation, it is also the case that differences in task switching performance may be due to variables other than age, one of which is individual differences in externalizing tendencies.

Task Switching in Externalizing Disorders During Development

Disorders that fall under the broad spectrum of externalizing disorders have been associated with deficits in mental flexibility and task switching. One study of attention deficit hyperactivity disorder (ADHD) reported larger switch costs in reaction time in unmedicated ADHD participants compared to controls (Cepeda, Cepeda, & Kramer, 2000). In contrast, another study reported no differences in switch costs between unmedicated ADHD participants (mean age = 12.8) and controls (mean age = 14.1) (Smith, Taylor, Brammer, Toone, & Rubia, 2006). In addition to evidence of attention switching deficits in children and adolescents with ADHD, there is data that indicates that children with ADHD inattentive subtype have slowed processing speed (e.g. Mayes, Calhoun, Chase, Mink, & Stagg, 2009); however, Kramer, Cepeda, &

Cepeda (2001), who studied children and adolescents with ADHD combined or hyperactive-impulsive subtype, reported that switch costs in ADHD are not affected by cue preparation, which is influenced by processing speed. The same methodological differences mentioned above may also contribute to the inconsistent findings in the ADHD literature. Additionally, there are sample-related differences between studies in terms of the ADHD subtypes that are studied, which further complicates comparisons. To date, there are no published studies of task switching in other forms of externalizing disorders; however deficits in set shifting as measured by perseverative responses and errors on the Wisconsin Card Sorting Test (Heaton, 1981) have been reported in adolescents with conduct disorder (e.g. Lueger & Gill, 1990), which raises the question of whether task switching deficits would be observed in adolescents who report externalizing behavior, but whose behaviors fall short of being classified as pathological.

Current Study

The current study was designed to elucidate the development of task switching during adolescence by 1) examining task switching independent of working memory and rule learning in a relatively large cross-sectional sample of typically developing participants ages 9 to 23; the task switching paradigm developed by Cools and colleagues (2003) was implemented; 2) examining how two components of task switching (processing speed and attention switching) change during adolescence, impacting overall task switching performance; and 3) in an exploratory aim, investigating associations between externalizing behaviors and task switching in this developmental sample. In addition to elucidating the development of task switching in typically developing adolescents, this study may have implications for psychopathological disorders which have particular relevance during childhood and adolescence. The specific aims and hypotheses of the study are as follows:

1. To examine how two components of task switching, processing speed and attention switching, change during adolescence in the context of a task switching paradigm that includes both components.

It was expected that the ability to switch tasks (i.e. attention switching), as measured by comparing performance on switch and non-switch trials regardless of preparatory interval, would mature earlier than processing speed ability, as measured by comparing performance on long and short CSI trials regardless of trial type, given the evidence that switching abilities reach adult levels of performance around age 12 (Cepeda et al., 2001; Crone et al., 2004) and that processing speed continues to improve throughout adolescence (Huizinga et al., 2006; Luna, Garver, Urban, Lazar, & Sweeny, 2004).

2. To examine the interaction between attention switching and processing speed in determining the overall quality of task switching performance as indexed by reaction times and error rates across adolescent development.

Given that previous research has shown that young adolescents ages 10-12 demonstrate larger switch costs on trials with short compared to long preparatory intervals (Cepeda et al., 2001), an interaction between attention switching (i.e. switch vs. non-switch) and processing speed (i.e. short vs. long preparatory interval) was expected.

3. To examine the relationship between externalizing tendencies, viewed from a dimensional perspective, and task switching performance across the range of typical development.

To date, there are no studies that have examined the associations between externalizing behaviors and task switching in typically developing adolescents; however, based on the task switching/set shifting deficits reported in adolescents with externalizing disorders, it was expected that externalizing tendencies would be associated with decrements in task switching performance. Given the findings suggesting that the task switching deficits in individuals with ADHD may not be associated with cue preparation, it was expected that externalizing tendencies would be associated with increased switch costs in reaction time and errors, but that this association would not be significantly affected by advance preparation, which is influenced by processing speed. The relationship between task switching performance and internalizing tendencies and total problem behaviors was also investigated to measure the discriminant validity of associations with externalizing behaviors.

Methods

Participants

Participants (n = 177; 79 males, 98 females), ages 9-23, were invited to participate in a longitudinal study of adolescent brain development. Children and adolescents were recruited from a database maintained by the University of Minnesota's Institute of Child Development, through posted campus advertisements, and via post cards sent to University employees inviting children's participation. Adult participants were recruited via posted campus advertisements. To be considered for the study, participants had to be right-handed, native English speaking individuals age 9-23 with normal or corrected-to-normal vision and hearing, have no problems moving their hands or arms, and must have had no serious birth complications, including prematurity, have no chronic medical conditions, no history of neurological conditions or head injury, and no history of learning, attention, or psychological disorders. Potential participants could not be taking any medication that may affect neural functioning (including antidepressants, sedatives, sleeping pills, anti-anxiety medications, anti-seizure medications, steroids, thyroid hormones, insulin, and some asthma and allergy medications), have minimal experience using alcohol, nicotine, and illicit substances, and have no conditions (e.g. pregnancy; braces on their teeth) or medical implants that would contraindicate MRI scanning (which is not reported upon here). Potential participants and their parents, in the case of minors, were screened during a brief telephone interview to ensure that they met the inclusion and exclusion criteria. Minors were asked about their histories of substance use, the possibility of pregnancy, their medication use, and if they had tattoos or piercings (to further ascertain MRI eligibility). All individuals who were deemed eligible for the study following the telephone screening visited the lab and were screened for a history of psychopathology via the Kiddie-SADS-Present and Lifetime Version (K-SADS-PL: Kaufman et al., 1997), a semi-structured diagnostic interview administered to the participant and the participant's parent separately, in the case of minors. Participants were excluded if they met full criteria for current or past Axis I psychopathology. Thus, this is not an asymptomatic sample but one that was diagnosis-free at enrollment. Some conditions that had high base rates, such as past histories of enuresis and simple phobias, were allowed, but only if they had not occurred within the past three years. All participants were screened for significant medical problems. Participants were excluded if they had a medical history that may have impacted typical development or neurological functioning. Data collection for the first wave of this study began in 2004 and continued for approximately two years. The study also has a longitudinal portion, which is ongoing. The analyses described here will focus on data obtained from the first wave of the study. See Table 2 for a summary of participant demographics.

Procedure

For their initial and longitudinal assessments, the participants completed a neuropsychological test battery, including a measure of task switching, and self-report behavioral and personality questionnaires (to be described). Verbal, performance, and full scale IQ were estimated by the Wechsler Abbreviated Scales of Intelligence (WASI: The Psychological Corporation, 1999).

Task Switching

The task, adapted from Cools et al. (2003), was programmed using the E-Prime stimulus presentation package and was administered on a Dell desktop computer using an E-prime microphone for response recording. See Figure 1 for an illustration of the task.

Each trial began with a fixation cross followed by a square outlined in red or green with a letter and a number inside. The participants were instructed to name the letter or number out loud as fast as possible without making mistakes. The latencies to respond were recorded by the microphone. Experimenters recorded the accuracy of each response. The color of the square served as the cue to indicate which task was to be performed (name the letter if the square is green, name the number if the square is red). Switch and non-switch trials were pseudorandomized such that not more than three trials of the same type were presented sequentially, and were presented in the same order to all participants. Switch costs were calculated by subtracting performance (reaction time and errors) on non-switch trials from switch trials. There were two conditions based on preparation time. In the long cue-stimulus interval (CSI) condition, a fixation cross appeared in the center of the screen for 200ms followed by the cue, which was presented 1100ms prior to the onset of the stimulus display. In the short CSI condition, a fixation cross appeared for 1150ms followed by the cue, which was presented 150ms prior to the onset of the stimulus display. The stimulus remained on the screen until participants responded with a maximum duration of 1500ms. Immediately after the response or 1500ms, the screen went blank and the next trial began. The long and short CSI trials were administered in blocks, as described below. Long and short CSI trials were administered in blocks rather than mixed in the same block, because prior research has indicated that individuals are better able to use preparation intervals when the trials are blocked (Rogers & Monsell, 1995). The stimulus-stimulus interval was held constant at 2800ms to isolate the effects of the preparation interval independent of the effects of distance from the last trial (Meiran, 1996).

Participants were instructed to respond as fast as possible without making too many mistakes. In the long CSI condition, they were instructed to use the time between the cue and the stimulus onset to prepare their responses. In the short CSI condition, the participants were told they would not have as much time to prepare, but they should still respond as quickly and accurately as possible. These instructions were given to the participant prior to the start of each block. They were also told that they would not have too much time to respond and that if they did not respond fast enough or loud enough for the microphone to record their response, a pink cross would appear prior to the next trial and they should respond faster or louder next time. Three practice blocks consisting of 60 trials in total were administered. In the first practice block, only the correct response was presented within the square and was administered to aid in acquisition of the stimulus-response selection rules. Two additional practice blocks were administered, one with the long CSI condition and one with the short CSI condition. Following the training session, four blocks consisting of 40 trials were administered. Two long CSI and two short CSI blocks were administered in the following order: long, short, long, short. The mean reaction time was displayed on the screen at the end of each block.

Median reaction times for correct trials and error rate for each trial type (i.e. switch and non-switch) and condition (long and short CSI) were calculated. As is customary in paradigms of this type, reaction times on incorrect trials were excluded from the analyses due to the inability to infer the cognitive processes occurring on incorrect trials, and trials following an error were excluded due to the possibility of post-error slowing (e.g. Cools et al., 2003; Crone et al., 2006a; Koch, 2005; Meiran & Marciano, 2002). Reaction time and error switch costs in the long and short CSI conditions were calculated.

Self-Report Measures

Several self-report measures were administered as part of the study, two of which will be described here. Participants ages 9-17 completed the Youth Self-Report (YSR) and young adults ages 18-23 completed the Adult Self-Report (ASR) of the Achenbach System of Empirically Based Assessment (ASEBA; Achenbach & Rescorla, 2001). Each questionnaire yields eight scales which dimensionally measure symptoms of DSM-IV psychopathology. An Internalizing scale is computed by summing scores on the Anxious/Depressed, Withdrawn/Depressed, and Somatic Complaints subscales. An Externalizing scale is computed by summing scores on the Rule-Breaking Behavior and Aggressive Behavior subscales for adolescents and the Rule-Breaking Behavior, Aggressive Behavior, and Intrusive subscales for adults. The Total Problem scale is derived by summing the Internalizing and Externalizing scales in addition to scores on the Social Problems, Thought Problems, Attention Problems, and Other Problems subscales for adolescents. For adults, the Total Problem scale is computed by summing the Internalizing and Externalizing scales, the Thought Problems, Attention Problems, and Other Problems subscales. Weak correlations have been found between adolescent and parental reports of internalizing and externalizing problems on the YSR in a non-psychiatric sample, with adolescents reporting more internalizing and externalizing behaviors than their parents (Seiffge-Krenke & Kollmar, 1998). As parental reports were not obtained from the adults in the current sample, self-reported problems will be used in the analyses to maintain consistency across the sample. Given that the number of items comprising each scale differed slightly between adolescents and adults, raw YSR/ASR variables were converted into percentages of the maximum score on each of the scales due to the difference in maximum possible score between the YSR and ASR scales.

Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS, Inc, Chicago, IL, USA), version 16.0 for Windows. Distributions of all variables were examined prior to analysis and those that did not meet the assumptions for parametric analysis, including error rates on the task switching paradigm and all of the YSR/ASR variables, were square root transformed.

To examine age-related differences in task switching performance variables, median reaction times (RTs) and error rates (calculated as [number of errors/trials] X 100) were analyzed using repeated measures ANOVA. This analytic strategy, as compared to regression analyses for example, was able to more clearly determine where age differences exist in task switching ability. The sample was divided into six age groups (9-10, 11-12, 13-14, 15-16, 17-18, and 19-23), which increased the opportunity to more precisely establish the point during adolescence when task switching reaches adult levels of performance. Additionally, the division of age groups makes the current results comparable to previous research (e.g. Cepeda et al., 2001; Crone et al., 2006a). The initial trial of each block, trials on which there was no response or those that were invalid (e.g. noise that was recorded by the microphone that was not intended to be a response), trials on which there was an error, and trials following an error (due to post-error slowing) were excluded from the reaction time analyses. Only trials on which an incorrect response (versus no response) was given were included in the error rate analyses. Across all analyses, an alpha level of .05 was used to determine whether findings were significant. Effect sizes will be presented as partial eta-squared (η_p^2, range = 0-1). Significant findings were followed up with repeated measures ANOVA, univariate ANOVAs, one-way ANOVAs, and paired-samples t-tests. Pairwise comparisons were Bonferroni corrected for multiple comparisons. Sex differences in task switching performance were examined given that there are sex differences in the trajectories of brain development during adolescence. Pearson correlations and hierarchical regressions were conducted to examine the relationship between self-reported behavioral variables and task switching performance.

Results

Demographics

The six age groups were similar in sex, parents' years of education, average household income, and verbal IQ (see Table 2). However, the 9-10 year-old group had a higher mean performance and full scale IQ than the groups ages 13-14, 15-16, and 19-23. Given that the difference in full scale IQ was driven by performance IQ (PIQ), PIQ was covaried in subsequent analyses to control for any potential confounding effects that PIQ may have on performance.

Age Differences in Task Switching Performance

Mean reaction times and error rates for the long and short CSI conditions are presented in Table 3 as a function of trial type and age group.

The number of trials available for the reaction time analyses was significantly different between age groups, F (5, 165) = 38.41, $p < .01$, but not sexes, F (1,165) = 1.0, ns. The sex X age group interaction was also nonsignificant, F (5,165) = 0.74, ns. The 9-10 and 11-12 year-old groups had significantly fewer trials included in the reaction time analyses compared to the older age groups and the 13-14 year-olds had significantly fewer trials available than participants ages 17-18 (see Table 4). Given that the number of trials available for the reaction time analyses was significantly different between age groups, the number of available trials was covaried in subsequent reaction time analyses to control for the potentially confounding effects of differences in the number of trials.

To examine the development of task switching and whether the age of maturation is different for switch costs in the long versus short CSI conditions, repeated measures ANOVAs were conducted to examine switch costs in reaction time and error rate in the long and short CSI conditions. Trial type (switch, non-switch), CSI (short, long), and block (block 1, block 2) were entered as the within-subjects variables and age group and sex served as between subjects variables. A main effect of trial type would indicate the presence of a switch cost. A main effect of CSI would indicate that performance is affected by advance preparation. An interaction between trial type and CSI would indicate that attention switching performance is affected by advance preparation, which is likely dependent on processing speed.

Error Rate

Controlling for PIQ, this analysis revealed a significant main effect of age group, indicating that error rates decreased with age (see Table 5 for statistics and Figure 2). The 9-10 year-olds made more errors than all other age groups, 11-12 year-olds made more errors than participants age 13 and older, and 13-14 year-olds made more errors than participants age 17 and older. There was also a main effect of sex indicating that males made more errors than females (see Figure 3). There was a significant main effect of block indicating that error rates were greater in block two than block one (see Figure 4). There was a significant block X age group effect (see Figure 5). A follow-up repeated measures ANOVA was conducted to examine the difference in error rates between blocks one and two within each age group. Follow-up analyses revealed that error rates were significantly greater in block two versus one in the 9-10 year-old group, F (1,22) = 7.14, $p < .05$, $\eta_p^2 = .245$. The difference in error rates between blocks one and two in 13-14 year-olds reached trend-level significance, F (1,23) = 3.03, $p < .10$, $\eta_p^2 = .116$, but was not significant for any other age group.

The analysis also yielded a three-way CSI X trial type X age group interaction (see Figure 6). The interaction was followed up with repeated measures ANOVAs comparing error rates in the long and short CSI conditions on switch and non-switch trials within each age group. There was a significant CSI X trial type interaction in the 9-10 year-old group, F (1,24) = 9.70, $p < .01$, $\eta_p^2 = .288$, and the 15-16 year-old group, F (1,26) = 7.54, $p < .05$, $\eta_p^2 = .225$. To clarify the nature of each interaction, follow-up repeated measures ANOVAs were conducted in the 9-10 and 15-16 year-old groups to examine switch costs (the difference between switch and non-switch conditions) in the short and long CSI conditions. Significant switch costs were present in the short (F (1,24) = 45.84, $p < .01$, $\eta_p^2 = .656$) and the long (F (1,24) = 11.17, $p < .01$, $\eta_p^2 = .318$) CSI conditions in the 9-10 year-old group; however the effect size for the short CSI condition was greater than the long CSI condition (see Figure 6c). Significant switch costs were observed in the long, but not the short CSI condition in the 15-16 year-old group, F (1, 26) = 16.09, $p < .01$, $\eta_p^2 = .382$ (see Figure 6d).

To summarize, error rates were relatively high in the 9-10 year-old and 11-12 year-old groups and significantly greater in block two versus block one in the 9-10 year-old group. Males had a significantly greater error rate than females. Significant switch costs were present in both CSI conditions in the 9-10 year-old group, although the effect was larger in the short CSI condition. Significant switch costs were found in the long, but not the short CSI condition in the 15-16 year-old group.

Reaction Time

Controlling for PIQ and number of trials, this analysis revealed a significant main effect of age group and a significant main effect of CSI (see Table 6 for statistics). Participants ages 9-10 were slower to respond than participants age 19-23, individuals ages 11-12 had slower reaction times than those ages 17 and older, and participants ages 13-14 had slower reaction times than participants age 19-23 (see Figure 7). Reaction times were longer on short versus long CSI trials (see Figure 8).

The analysis also revealed a significant CSI X age group interaction (see Figure 9) potentially indicating age-related differences in processing speed. A follow-up repeated measures ANOVA comparing reaction times on long and short CSI trials within each age group indicated that reaction times were significantly longer on short versus long CSI trials in all groups (9-10 year-old group, F (1,22) = 32.86, $p < .001$, $\eta_p^2 = .599$; 11-12 year-old group, F (1,19) = 35.03, $p < .001$, $\eta_p^2 = .648$; 13-14 year-old group, F (1,24) = 51.20, $p < .001$, $\eta_p^2 = .681$; 15-16 year-old group, F (1,26) = 99.32, $p < .001$, $\eta_p^2 = .793$; 17-18 year-old group F (1,34) = 56.15, $p < .001$, $\eta_p^2 = .623$; and 19-23 year-old group, F (1,44) = 77.14, $p < .001$, $\eta_p^2 = .628$). Follow-up univariate ANOVAs were conducted to examine whether there were age-related differences in reaction time in the short and long CSI conditions when examined separately. These analyses revealed that there was a significant effect of age group in the short CSI condition. Pairwise comparisons in the short CSI condition indicated that 9-10 and 11-12 year-olds were slower than those age 15 and older and that 13-14 year-olds were slower than individuals age 19-23, $\underline{F}$ (5, 166) = 5.81, $\underline{p} < .001$; $\eta_p^2 = .149$. There was no significant effect of age group in the long CSI condition.

To summarize, reaction times were longer on short versus long CSI trials in each age group, however, the effect sizes varied between age groups. Adult levels of performance were seemingly reached before ages 9-10 in the long CSI condition. In contrast, adult levels of performance were reached by ages 15-16 in the short CSI condition. The results suggest that the age-related differences in CSI reaction times were primarily driven by processing speed ability given the absence of age-related differences in the long CSI condition, which places lower demands on processing speed.

There was a significant age group X sex interaction (see Figure 10). Follow-up one-way ANOVAs showed that females age 19-23 had slower reaction times than males of the same age, $\underline{F}$ (1,44) = 9.34, $\underline{p} < .01$. There was a significant trial type X block interaction. Follow-up repeated measures ANOVAs indicated that reaction times on switch trials were significantly greater than non-switch trials in block 1, $\underline{F}$ (1, 174) = 7.86, $\underline{p} < .001$, $\eta_p^2 = .044$, but not block 2, $\underline{F}$ (1, 174) = 0.54, $\underline{p} > .10$, $\eta_p^2 = .003$ (see Figure 11).

The analysis revealed a significant CSI X trial type X age group X sex interaction (see Tables 7 and 8 for follow-up F statistics for each sex). A follow-up repeated measures ANOVA in males showed a significant main effect of age group, indicating that 9-10, 11-12, and 13-14 year-olds were slower than participants age 19-23. There was also a significant main effect of CSI in males indicating that reaction times were greater for short versus long CSI trials. All other main effects and interactions were nonsignificant.

Follow-up repeated measures ANOVA in females showed a significant CSI X age group interaction in females (see Figure 12). Follow-up repeated measures ANOVA comparing reaction time on long and short CSI trials within each age group indicated that reaction times were significantly longer on short versus long CSI trials in the 9-10 year-old group, F (1,14) = 32.83, $p < .001$, $\eta_p^2 = .701$, 11-12 year-old group, F (1,6) = 12.13, $p < .05$, $\eta_p^2 = .669$, 13-14 year-old group, F (1,10) = 24.35, $p < .01$, $\eta_p^2 = .709$, 15-16 year-old group, F (1,13) = 96.46, $p < .001$, $\eta_p^2 = .881$, 17-18 year-old group, F (1,17) = 32.07, $p < .001$, $\eta_p^2 = .654$, and 19-23 year-old group, F (1,30) = 37.23, $p < .001$, $\eta_p^2 = .554$. Follow-up univariate ANOVAs were conducted to examine whether there were age-related differences in reaction time in the short and long CSI conditions in females. These analyses revealed that there was a significant effect of age group in the short CSI condition. Pairwise comparisons in the short CSI condition indicated that 9-10 year-olds were slower to respond than participants age 15-16 and 17-18 and that 11-12 year-olds were slower to respond than participants age 17-18, F (5,88) = 3.47, $p < .001$; $\eta_p^2 = .165$. Age-related differences in the long CSI condition were nonsignificant.

There was a significant trial type X age group interaction in females (see Figure 13). Follow-up repeated measures ANOVA comparing reaction time on switch and non-switch trials within each age group indicated that reaction times were significantly longer on switch versus non-switch trials only in the 9-10 year-old group, F (1,14) =

12.25, p < .01, $\eta_p^2 = .467$. Follow-up univariate ANOVAs were conducted to examine whether there were age-related differences in reaction time in the switch and non-switch conditions in females. These analyses revealed that there was a significant effect of age group in the switch condition, F (5,88) = 2.40, $p < .05$; $\eta_p^2 = .120$, however, pairwise comparisons failed to reach significance. Age-related differences in the non-switch condition were nonsignificant.

Follow-up repeated measures ANOVA in females revealed a significant CSI X trial type X age group interaction (see Figure 14). This interaction was followed-up with repeated measures ANOVA comparing reaction times on short and long CSI trials in switch and non-switch conditions within each age group. These analyses revealed a significant CSI X trial type interaction in only 9-10 year-old group, F (1,14) = 27.65, $p < .001$, $\eta_p^2 = .664$. A follow-up repeated measures ANOVA examining switch costs (difference in reaction time between switch and non-switch trials) in short and long CSI trials revealed that significant switch costs were observed in the short, but not the long condition in the 9-10 year-old group, F (1,14) = 20.81, $p < .001$, $\eta_p^2 = .598$.

To summarize the major sex differences in the task switching reaction time data, there were no age-related differences when examining CSI or trial type in males; however, there was a CSI X trial type X age group interaction in females. Switch costs were significant on short, but not long CSI trials in the 9-10 year-old female group, indicating that the youngest age group demonstrated a decrement in performance due to changing tasks and that this decrement was greater when faster processing speed was required.

The repeated measures ANOVA examining switch costs in reaction time and error rate in the long and short CSI conditions described above was repeated to include both correct and incorrect trials as an exploratory analysis. The overall pattern of findings remained the same when incorrect trials were included in the analysis.

There was no evidence for a speed-accuracy tradeoff in either the entire sample or within each age group across all task trials. Pearson correlations between reaction times and error variables indicated that faster reaction times were correlated with fewer errors (see Table 9).

There were no significant interactions between the covariates (PIQ and total trials) and any of the variables within the repeated measures ANOVA that examined switch costs in reaction time and error rate in the long and short CSI conditions. There was a significant main effect of total trials in the reaction time analyses, $F(1,160) = 7.74$, $p < .01$ and a significant main effect of PIQ in the error rate analyses, $F(1,163) = 11.76$, $p < .01$.

To summarize the major reaction time results, regardless of CSI or trial type, reaction time decreased with age indicating faster information processing with increased development. Across all ages, reaction times were significantly greater on short versus long CSI trials indicating that performance slowed when preparation times were shortened; however, the effect sizes varied across age groups ranging from a medium effect size in 9-10 year-olds to a strong effect size in 15-16 year-olds. Additionally, reaction times on short CSI trials reached adult levels of performance later in development than reaction times on long CSI trials, suggesting age-related improvements in processing speed. There were sex differences in task switching reaction time variables with the majority of the findings occurring within the female group. Within females, the 9-10 year-old group had significant switch costs on short, but not long CSI trials.

Effect of Trial Sequence on Switch Costs

To examine the effect of task load on task switching performance, repeated measures ANOVAs were conducted examining error rates and reaction times on switch trials occurring after one non-switch trial and switch trials occurring after two consecutive non-switch trials. CSI (short, long) and task load (switch after one non-switch trial, switch after two consecutive non-switch trials) were entered as the within-subjects variables. Age group and sex served as the between subjects variables.

Controlling for PIQ, the error rate analysis revealed a significant main effect of task load, $\underline{F}$ (1,160) = 5.11, $\underline{p} < .05$, $\eta_p^2 = .030$, indicating that error rates were significantly higher on switch trials following one compared to two consecutive non-switch trials (see figure 15). There was also a significant main effect of age group and CSI X age group interaction that mirrored those reported in Table 4.

Controlling for PIQ and total trials, the reaction time analysis did not reveal any significant effects related to task load. Significant main effects of age group and CSI and significant age group X sex and CSI X age group interactions mirrored those reported in Table 5.

Self-report behavioral correlates

Pearson correlations were conducted to examine the association between self-reported behavioral variables and task switching performance. The ranges of percent of the maximum score for the behavioral variables were as follows: externalizing = 0 -

42%, internalizing = 0 – 50% and total problems = 0 – 38%. Externalizing, internalizing, and total problem percents were positively correlated with switch costs in errors in the long condition. Internalizing percent was positively correlated with error rate on long switch trials (see Table 10). Externalizing, internalizing, and total problem percents were not significantly correlated with switch costs in reaction time. Externalizing and internalizing percents were significantly correlated with each other, r (174) = .515, p < .001, and as would be expected, with total problem percent, r = (174) = .822, p < .001 and r (173) = .838, p < .001, respectively.

Regression models

Hierarchical linear regressions examined whether self-reported behavioral variables contributed independently to task switching performance. First, age, sex, PIQ, and externalizing and internalizing scores were entered in successive blocks to determine their ability to predict reaction times and error rates on each trial type and CSI combination (i.e. long switch, short switch, long non-switch, short non-switch). These regressions only revealed that age accounted for a significant proportion of the variance in each variable and that externalizing accounted for a significant amount of variance in long non-switch error rate indicating that higher reports of externalizing behavior were associated with fewer errors on long non-switch trials.

Age, sex, PIQ, and externalizing and internalizing scores were entered in successive blocks to determine their ability to predict switch costs in reaction times and errors in the long and short preparatory conditions. Age, sex, and PIQ yielded a significant model of switch costs in error rate in the short preparatory condition F (4,169) = 4.15, p < .01. Age accounted for a significant proportion of the variance in switch costs in error rate in the short CSI condition, indicating that switch costs decreased with increasing age. Age, sex, PIQ, and externalizing scores yielded a marginally significant model of switch costs in error rate in the long preparatory condition F (4,169) = 2.34, p = .058. Externalizing behavior accounted for a significant proportion of the variance in switch costs in errors in the long CSI condition, indicating that participants who reported more externalizing behavior had greater switch costs in errors than those who reported less externalizing behavior. However, externalizing scores failed to account for a significant proportion of variance when internalizing scores were included in the model (see Table 11).

Age, sex, and PIQ yielded a significant model of switch costs in reaction time in the short preparatory condition F (3,168) = 10.39, p < .001. In this model, age accounted for a significant proportion of the variance in switch costs in reaction time in the short CSI condition, indicating that older participants had smaller switch costs. Adding externalizing and internalizing scores did not improve the model fit. None of the variables yielded a significant model of switch costs in reaction time in the long CSI condition (see Table 12).

Number of trials was added to the first step of the reaction time regression models given that number of trials was covaried in the reaction time analyses described above. The results remained unchanged when number of trials was added to the models.

Discussion

One of the main goals of this study was to examine changes in task switching ability across adolescence and to examine the development of two of the cognitive mechanisms that underlie task switching, attention switching and processing speed. An additional exploratory goal of the study was to examine the influence of externalizing behaviors on task switching. This aim was exploratory given the non-clinical low-risk nature of the sample. It was predicted that 1) attention switching ability would mature earlier than processing speed, 2) there would be an interaction between attention switching and processing speed, and 3) externalizing tendencies would be associated with increased switch costs in reaction time and errors, but that this association would not be significantly affected by processing speed. The results of the study only partially supported the hypotheses; however, they lend support to the notion that task switching is a complicated, multi-faceted cognitive process by demonstrating that two cognitive processes that underlie task switching, attention switching and processing speed, develop at different rates and that there may be sex differences in task switching development.

The data support the hypothesis predicting that different cognitive components of task switching develop at different rates. The results demonstrated that attention switching matures by ages 9-10 in males and ages 11-12 in females. Although this is the first developmental study of task switching to employ an object switching paradigm, the present findings regarding the development of attention switching ability is consistent with previous studies that concluded that task switching ability reaches adult levels of performance around age 12 (Cepeda et al., 2001; Crone, et al., 2004; Crone et al., 2006a; Crone et al., 2006b; Morton et al., 2009). In contrast, the age-related differences in reaction time revealed that adult levels of performance were reached later in adolescence in the short compared to the long CSI condition in females, suggesting that processing speed continues to increase into adolescence. These findings suggest that the age-related differences in CSI may be primarily driven by processing speed given the absence of age-related differences in the long CSI condition, which places lower demands on processing speed. Thus, the ability to efficiently switch attention regardless of advance preparation appears to be mature by young adolescence (i.e. ages 9-10 in males and 11-12 in females) while the ability to efficiently activate the upcoming task set, which is dependent on processing speed, continues to improve into adolescence (i.e. ages 13-14 in females). The findings regarding the development of processing speed as measured by comparing reaction times on short and long CSI trials are not entirely consistent with the existing literature. Previous studies have shown that processing speed, measured by simple reaction time tasks and tasks that have cognitive demands (e.g. Stroop Test word reading and color naming blocks), continues to develop into mid- to late adolescence (e.g. Huizinga et al., 2006; Luna et al., 2004). The comparison of reaction times on short and long CSI trials suggests an earlier age of maturation than what the majority of previous research indicates. Also, it was unexpected that males would fail to show decreases in processing speed beyond age 9-10 as there is literature that suggests that females have superior processing speed abilities compared to males during adolescence (Camarata & Woodcock, 2006). Additionally, males have a more protracted rate of white matter development during adolescence compared to females (Lenroot et al., 2007), which would suggest that processing speed would continue to develop during adolescence. It is possible that the sex differences in processing speed found in this study were an isolated effect and may not be a replicable finding.

Another way to interpret the results in terms of the development of processing speed and perhaps reconcile the discrepancy between the current findings and previous studies would be to consider the age-related differences in reaction time, regardless of trial type or CSI condition. In the whole sample and in the males, reaction times continued to decrease significantly until age 15-16, which is consistent with previous literature showing that processing speed continues to improve into mid- to late adolescence (Huizinga et al., 2006; Luna et al., 2004). Although the main effect of age only reached a trend level of significance in the females, the developmental trajectory appeared similar to that of the entire sample. The age-related differences in reaction time between short and long CSI trials, which revealed that processing speed continued to develop until age 15-16 in the whole sample provides further evidence that processing speed improves into mid-adolescence. Taken together, the age-related differences in overall reaction time and the age-related differences in reaction time on short and long CSI trials in the whole sample are more consistent with the existing literature regarding the developmental trajectory of processing speed than the sex-related differences in processing speed observed in the current study.

An examination of how attention switching and processing speed interact revealed significant switch costs in error rate in both the long and short CSI conditions in the 9-10 year-old group; however, the effect was larger in the short CSI condition, suggesting that attention switching resulted in a greater reduction in accuracy under conditions of higher processing speed demands. Additionally, significant switch costs in reaction time were present on short, but not long CSI trials in 9-10 year-old females. These findings indicate that the youngest females demonstrated a decrement in performance when attention switching was required, and that the decrease in performance was greater when higher demands were placed on processing speed. Thus, all 9-10 year-olds experienced a decrease in accuracy during attention switching, which may have been greater under higher processing speed demands. Additionally, 9-10 year-old females benefitted from advance preparation as their decrement in reaction time performance was greater when faster processing speed was required. It is possible that this effect would have been observed in males as well if the number of males and females in the 9-10 year-old group had been more equivalent.

The current results indicate that young adolescents have the ability to appropriately switch their attention; however, accuracy in both sexes and efficiency in females decrease when the amount of time they have to prepare their response decreases, which reflects increased demands on information processing speed. The interaction of attention switching and increased processing speed demands produced a significant decrement in performance only in the youngest age group. These results suggest that processing speed facilitates more efficient switching as attention switching ability improves with age. Perhaps if the attention switch was more cognitively demanding, processing speed would have impacted performance in the older age groups as well. Participants older than ages 9-10 were able to switch attention without significant decrements in performance, so it seems that processing speed had a larger impact on performance than attention switching in all but the youngest participants. As will be discussed more thoroughly below, immature connectivity between brain regions in young adolescents likely plays an important role in performance decrements in attention switching and slower processing speed. It is also possible that older adolescents employ different strategies that contribute to successful and efficient task switching. For example, there is evidence that task-relevant verbalization decreases switch costs and that children age 7-9 show greater decrements in performance when task-relevant verbalization is prevented compared to adolescents and young adults (Kray, Eber, & Karbach, 2008). It is possible that young adolescents have not yet successfully adopted such strategies that improve task switching performance.

The lack of age-related differences in males in CSI or trial type suggests earlier maturation of attention switching, task set-activation, and perhaps processing speed abilities, and potentially the task-relevant brain regions, in males compared to females. This possibility is consistent with results from a study that found an increase in age-correlated inferior and medial prefrontal activation in females and an increase in age-correlated parietal activation in males during task switching (Christakou et al., 2009). The authors of this study suggested that males have a more mature activation pattern in parietal regions and that females have a more mature activation pattern in frontostriatal regions (Christakou et al., 2009). Given that the paradigm used in this study measures attention switching and the evidence that attention switching is associated with increased recruitment of the parietal cortex (Ravizza & Carter, 2008), it is possible that the task switch in the current paradigm engages the parietal cortex and the frontostriatal network, but is more heavily dependent on parietal activation. If so, the sex differences in attention switching observed in this study could reflect more mature parietal activation in males relative to females. It is difficult to reconcile the lack of age-related differences in CSI (i.e. processing speed) in males given the literature that suggests that processing speed continues to develop across adolescence in males and females (Camarata & Woodcock, 2006; Lenroot et al., 2007).

Developmental neuroimaging studies of task switching have suggested that age-related differences in neural activation during task switching reflect the maturation of neural networks that subserve task switching (e.g. Crone et al., 2006b; Rubia et al., 2006). It is likely that neuronal pruning and increases in white matter integrity in the dorsolateral fronto-parieto-striatal system underlie the age-related changes in attention switching and processing speed observed here. The difference in age of maturation of attention switching and processing speed is consistent with the suggestion that the capacity for executive function emerges during childhood, but that the efficiency of executive functioning continues to increase throughout adolescence as a result of increased information processing speed, which is subserved by increases in white matter integrity and neuronal pruning (Luna, 2009). It is also likely that the development of neurotransmitter systems influences task switching development. Cools et al. (2003) demonstrated that performance on short CSI trials is dopamine-modulated, so it is possible that the age-related improvements in task performance, particularly processing speed, are also associated with the maturation of dopaminergic networks.

A final, albeit exploratory, goal of the study was to examine the extent to which externalizing and internalizing behaviors affect task switching performance in adolescents. There was modest evidence suggesting that individuals who report more externalizing behavior experience significant decrements in attention switching accuracy under conditions of lower processing speed demands. Perhaps participants who reported more externalizing behavior found the long preparatory interval less engaging than the short preparatory interval, which may account for the wider discrepancy in accuracy between task switches and non-switches. This finding is consistent with the literature that indicates that externalizing disorders (e.g. ADHD) are associated with deficits in task switching and mental flexibility (Cepeda et al., 2000; Lueger & Gill, 1990). The lack of more significant findings may be explained by the possibility that the degree of externalizing behavior reported by the participants was not severe enough to have an impact on task switching performance. The participants in this study were purposely selected to have no history of psychopathology, so it is possible that externalizing behavior would have a larger influence in individuals with clinically significant externalizing behavior problems.

The results of the study have broader implications for understanding adolescent behavior. Given that task switching ability in young adolescents is affected by processing speed, it may be important to provide ample transition time between subjects or classes at school. Expecting children or adolescents under the age of 11 or 12 to be able to rapidly switch their attention from mathematical calculations to reading comprehension, for example, may not be reasonable. Similarly, timed exams that contain different types of problems may not be appropriate for children or young adolescents, depending on what the exam is intended to assess. The results of this study may provide parents more with more evidence for why their young teens should not multitask while working on homework as these findings can at least partially explain why adolescents, particularly young adolescents, may not be as accurate or efficient in completing their assignments if they are watching television, texting, or talking on the phone. Task switching appears to be a fairly mature cognitive process by mid-adolescence, which likely benefits adolescents as they are increasingly in situations where rapid attention switching is necessary. Driving a vehicle is a skill that requires accurate and efficient task switching ability to successfully change lanes, shift gears, and avoid unexpected obstacles in the road. Only considering how cognitive flexibility affects driving performance, the current driving age of 16 in most states seems appropriate given that the results of this study indicate that adolescents have reached adult levels of task switching ability by this age; however, this statement should be qualified to indicate that the results of this study suggest that 16 year-olds have the capacity for efficient task switching ability to drive in non-distracting environments. Real life driving situations often involve other individuals or music in the vehicle and the temptation of using a cell phone. Although young adolescents do not usually drive vehicles, riding a bike on a busy street is an activity that they may engage in and is similar to driving, so parents would be wise to emphasize the importance of maintaining focus and eliminating potentially distracting stimuli, like cell phones, while biking. Finally, the results showed that there were reaction time switch costs in the first, but not the second block of trials, which suggests that individuals become more efficient at task switching with practice. It is possible that adolescents may have more difficulty with task switching in novel situations, but that their task switching ability may improve as they gain experience in a situation.

Overall, there were several unexpected findings in both the error rate and reaction time analyses, including a lack of a main effect of CSI and trial type in the error rate data and a main effect of trial type in the reaction time data. The lack of effect of advance preparation on error rates is consistent with other studies that have found that advance preparation had a larger impact on reaction time than error rates (Cepeda et al., 2001; Cools et al., 2003). It was surprising that there was no significant difference in error rates between switch and non-switch trials across the whole sample. It is possible that switching between responding to a letter and a number was not sufficiently difficult to invoke a switch cost in this sample comprised of adolescents and young adults. The task was adapted from Cools et al. (2003), who studied older adults (mean age = 63.8). It has been demonstrated that switch costs increase during older adulthood (early- to mid-60s) (Cepeda et al., 2001; Meiran, Gotler, & Perlman, 2001; Reimers et al., 2005), so it may not be surprising that, although Cools et al. (2003) observed switch costs in error rate, such an effect was not evident in the current study given that young, rather than older adults were included in the study. The fact that reaction times across all blocks were not impacted by task switching was also unexpected; however, it was the case that reaction times were significantly longer on switch compared to non-switch trials in the first set of blocks. The absence of switch costs in the second set of blocks could be explained by practice effects as previous studies have reported significant reductions in switch costs with practice (Cepeda et al., 2001; Koch, 2005).

There are several limitations of this study that should be acknowledged. One limitation of the task is that it may not have been sufficiently cognitively demanding to observe significant attention switching effects in the older participants. Perhaps if the participants had been required to state whether the letter was a vowel or a consonant and the number was even or odd (Rogers & Monsell, 1995), there would have been significant interactions between attention switching and processing speed in some of the older age groups. Although prior research has indicated that individuals are better able to use preparation intervals when the trials are blocked (Rogers & Monsell, 1995), it would have been interesting to include a block of trials that randomly mixed short and long preparatory intervals, which may reflect more accurately the task switching demands that individuals encounter in an unpredictable, natural environment. A larger sample size would be useful to determine if the sex differences observed in this study are isolated findings or if they would be replicated in future studies. Additionally, inclusion of individuals with clinically significant externalizing behaviors (e.g. conduct disorder, oppositional defiant disorder, ADHD) would be informative in examining the potential impact that externalizing behaviors have on task switching ability. Using neuroimaging techniques to examine correlations between age and sex differences in the cognitive components that underlie task switching and brain structure and function would further elucidate how neural development contributes to age-related behavioral changes in task switching. Also, given that the task used in this study is modulated by dopamine, it may be informative to investigate associations between genotypic variation that affects dopamine functioning and task switching performance in adolescents, which may further our understanding of how the maturation of neurotransmitter systems contribute to task switching development. Finally, this paradigm allows switch costs to be examined under relatively “pure” cognitive conditions without complex manipulations of additional cognitive processes, such as stimulus-response compatibility and working memory. Examining the basic cognitive processes that subserve task switching and other executive functions using both behavioral tasks and neuroimaging techniques would reveal the neural basis of brain-behavior relationships and could lead to a better understanding of the development of more complex executive functioning (Luna, 2009). While the paradigm used in this study is informative regarding the nature of the development of the underlying cognitive processes that subserve task switching ability in the laboratory, it is unknown how task switching ability measured here translates to task switching abilities in real life situations. It would be informative to know how performance on laboratory tasks predicts real life functioning. Perhaps more complex designs may be better suited to address task switching ability that is required in real life situations, as real life situations likely require more complex cognitive processing.

The current study provides evidence that task switching is a complicated executive function and emphasizes the importance of understanding the development of the different cognitive components that underlie different forms of task switching. The results showed that the different cognitive components that underlie task switching ability develop at different rates. Attention switching ability appears to be mature by early adolescence; however, the ability to efficiently activate the upcoming task set, which is likely dependent on processing speed, continues to increase until mid-adolescence. Although there were sex differences in the development of attention switching and processing speed, they were not consistent with previous literature and should be interpreted with caution. These data clarify the nature of task switching development in adolescence by revealing how age-related changes in two cognitive components that underlie task switching ability contribute to overall task switching performance. The results also have implications for broader adolescent behavior and education. Specifically, it is important to consider what is reasonable to expect of adolescents given their capacity for accurate and efficient cognitive flexibility in structuring their exams, classes, and homework environments as well as increasing safety in recreational activities, such as biking, and while driving.

Table 1
Summary of the processes that can be measured by cued task switching paradigms

Analytic Comparison	Process
Switch vs. non-switch	Attention switching
Short vs. long CSI	Processing speed
Switch cost long vs. switch cost short	Integration of attention switching and processing speed

Table 2
Demographics

Characteristic	Total Sample	Age 9-10	Age 11-12	Age 13-14	Age 15-16	Age 17-18	Age 19-23	Group Difference
N	177	25	20	25	27	35	45	
% female	55.4	68.0	35.0	44.0	51.9	51.4	68.9	χ^2 = 9.96 (ns)
% Caucasian	86.9	88.0	85.0	92.0	96.3	82.9	81.4	χ^2 = 20.23 (ns)
Age (years)	16.08 (4.01)	9.81 (.40)	11.97 (.64)	13.96 (.51)	15.87 (.42)	18.03 (.54)	21.17 (1.25)	F (5,174) = 882.69, p < .001
Mother's education (years)	15.74 (1.97)	15.64 (1.93)	15.85 (1.04)	16.22 (1.65)	16.00 (1.71)	15.76 (2.03)	15.29 (2.52)	F (5,167) = .83 (ns)
Father's education (years)	16.12 (2.93)	15.72 (3.06)	17.16 (2.48)	15.54 (2.55)	16.22 (3.15)	16.70 (2.85)	15.71 (3.10)	F (6,166) = 1.11 (ns)
Family income (US $)	98,124 (74,659)	95,120 (49,252)	96,842 (52,207)	95,870 (55,343)	101,154 (98,390)	118,519 (113,847)	83,636 (48,352)	F (5,150) = .66 (ns)
WASI VIQ	114.61 (10.54)	117.33 (12.21)	115.90 (13.04)	111.72 (2.22)	114.04 (9.79)	113.03 (10.61)	115.76 (8.16)	F (5,173) = 1.33 (ns)
WASI PIQ	113.82 (12.09)	121.88 (17.21)	114.00 (15.71)	111.60 (10.03)	109.67 (11.96)	115.57 (8.48)	111.80 (1.25)	F (5,173) = 4.65, p < .01
WASI FSIQ	116.01 (10.75)	121.92 (13.61)	116.85 (15.0)	113.16 (9.53)	113.67 (10.72)	116.11 (8.96)	115.40 (7.66)	F (5,173) = 3.08, p < .05
YSR/ASR Externalizing (%)	10.23 (.08)	5.79 (.05)	8.44 (.07)	11.75 (.10)	12.44 (.07)	15.25 (.10)	7.36 (.06)	F(5,173) = 6.94, p < .001
YSR/ASR Internalizing (%)	11.55 (.10)	11.69 (.10)	13.87 (.12)	11.29 (.07)	14.87 (.13)	12.28 (.10)	7.95 (.08)	F(5,173) = 2.44, p < .05
YSR/ASR Total Problems (%)	12.65 (.08)	9.40 (.07)	13.68 (.08)	13.96 (.08)	15.06 (.08)	15.55 (.08)	9.52 (.07)	F(5,173) = 4.49, p < .01

Unless otherwise indicated, values represent means +/- one standard deviation (in parentheses); For the YSR/ASR scores, values represent percents (%) of the total maximum score on each scale.

Table 3
Task Switching Performance Data Across Age Groups

	Short CSI		Long CSI	
	RT (ms)	Error Rate (%)	RT (ms)	Error Rate (%)
9-10 year-olds				
Switch trials	854.8 (37.7)	27.3 (1.8)	654.6 (29.1)	17.6 (1.4)
Non-switch trials	766.5 (30.8)	18.9 (1.2)	637.5 (27.2)	14.7 (0.9)
Switch costs	88.3 (22.4)	8.4 (1.9)	17.1(14.9)	2.9 (1.5)
11-12 year-olds				
Switch trials	790.4 (29.0)	16.3 (1.9)	653.2 (22.4)	12.7 (1.4)
Non-switch trials	756.1 (23.7)	8.4 (1.2)	652.6 (20.9)	7.8 (1.0)
Switch costs	34.3 (17.2)	7.9 (1.9)	0.6 (11.5)	4.9 (1.5)
13-14 year-olds				
Switch trials	731.6 (23.9)	8.9 (1.6)	603.6 (18.4)	8.0 (1.2)
Non-switch trials	704.4 (19.6)	5.8 (1.0)	601.1 (17.3)	4.6 (0.8)
Switch costs	27.2 (14.2)	3.1 (1.6)	2.5 (9.5)	3.4 (1.3)
15-16 year-olds				
Switch trials	685.6 (23.5)	5.9 (1.5)	589.4 (18.1)	5.4 (1.2)
Non-switch trials	663.8 (19.2)	5.1 (1.0)	587.5 (16.9)	2.1 (0.8)
Switch costs	21.8 (14.0)	0.8 (1.6)	1.9 (9.3)	3.3 (1.2)
17-18 year-olds				
Switch trials	672.4 (21.4)	4.4 (1.3)	593.7 (16.5)	4.6 (1.0)
Non-switch trials	649.2 (17.5)	4.4 (0.9)	589.0 (15.4)	1.9 (0.7)
Switch costs	23.2 (12.7)	0.0 (1.4)	4.7 (8.4)	2.7 (1.1)
19-23 year-olds				
Switch trials	624.9 (20.3)	5.0 (1.3)	556.4 (15.6)	3.7 (1.0)
Non-switch trials	617.3 (16.6)	3.2 (0.8)	561.0 (14.6)	2.2 (0.7)
Switch costs	7.6 (12.1)	1.8 (1.3)	-4.6 (8.0)	1.5 (1.0)

Values represent means (+/- one SE). Reaction times include correct trials and trials on which there was a valid response (excluding noise that was recorded by the microphone that was not intended to be a response). Trials on which there was an error and trials following an error were excluded from the reaction time analyses. Error rates were calculated as [number of errors/trials] X 100.

Table 4
Trials excluded and total number of trials included in the reaction time analyses by age group

	Errors + Trials After Error	No Response	Invalid Response	Number of Trials Included
9-10	73.8 (33.8)	13.8 (9.8)	5.8 (7.3)	66.5 (39.6)
11-12	45.5 (23.0)	6.6 (5.6)	3.9 (3.3)	104.1 (28.0)
13-14	27.8 (20.0)	5.8 (5.2)	1.7 (2.3)	124.7 (22.2)
15-16	20.6 (14.3)	4.6 (6.4)	3.9 (5.3)	130.9 (20.3)
17-18	14.3 (9.1)	2.9 (5.3)	1.7 (2.9)	141.1 (12.9)
19-23	12.8 (10.1)	5.5 (8.1)	3.8 (7.6)	137.9 (18.3)

Values represent means (+/- one SD); statistics are presented in the text.

Table 5
Analysis of variance results for error rate by age group, sex, CSI, trial type, and block

Variable	F	df	p	η_p^2
Age group	**38.27**	**5, 163**	**< .001**	**.540**
Sex	**5.63**	**1, 163**	**< .05**	**.033**
CSI (short vs. long preparation)	.01	1, 163	.924	.000
Trial Type (switch vs. non-switch)	2.80	1, 163	.096	.017
Block	**15.09**	**1, 163**	**< .001**	**.085**
CSI X Age group	1.36	5, 163	.244	.040
CSI X Sex	1.72	1, 163	.191	.010
CSI X Trial Type	.329	1, 163	.567	.002
CSI X Block	.093	1, 163	.760	.001
Trial Type X Age group	1.84	5, 163	.108	.053
Trial Type X Sex	.29	1, 163	.594	.002
Trial Type X Block	1.18	1, 163	.279	.007
Block X Age group	**5.60**	**5, 163**	**< .001**	**.147**
Block X Sex	.60	1, 163	.440	.004
Block X Age group X Sex	.92	5, 163	.472	.027
Age group X Sex	1.54	5, 163	.180	.045
Preparatory X Age group X Sex	1.15	5, 163	.339	.034
Trial Type X Age group X Sex	.70	5, 163	.626	.021
CSI X Trial Type X Age group	**3.38**	**5, 163**	**<.01**	**.094**
CSI X Trial Type X Sex	.30	1, 163	.585	.002
CSI X Block X Age group	.39	5, 163	.853	.012
CSI X Block X Sex	.32	1, 163	.574	.002
CSI X Trial Type X Block	.04	1, 163	.952	.000
Trial Type X Block X Age group	1.16	5, 163	.334	.034
Trial Type X Block X Sex	.07	1, 163	.788	.000
CSI X Trial Type X Age group X Sex	.73	5, 163	.599	.022
CSI X Block X Age group X Sex	.11	5, 163	.990	.003
Trial Type X Block X Age group X Sex	1.42	5, 163	.219	.042
CSI X Trial Type X Block X Age group	1.83	5, 163	.110	.053
CSI X Trial Type X Block X Sex	.33	1, 163	.568	.002
CSI X Trial Type X Block X Age group X Sex	.36	5, 163	.875	.011

Note: This table does not include statistics regarding the main effects or interactions related to the covariate of PIQ.

Table 6
Analysis of variance results for reaction times by age group, sex, CSI, trial type, and block

Variable	F	df	p	η_p^2
Age group	**5.20**	**5, 160**	**< .001**	**.140**
Sex	0.36	1, 160	.574	.002
CSI	**4.66**	**1, 160**	**< .05**	**.028**
Trial Type	1.24	1, 160	.267	.008
Block	0.23	1, 160	.632	.001
CSI X Age group	**3.46**	**5, 160**	**< .01**	**.097**
CSI X Sex	1.43	1, 160	.233	.009
CSI X Trial Type	0.53	1, 160	.818	.000
CSI X Block	0.45	1, 160	.502	.003
Trial Type X Age group	1.57	5, 160	.171	.047
Trial Type X Sex	0.10	1, 160	.756	.001
Trial Type X Block	**8.59**	**1, 160**	**< .01**	**.051**
Block X Age group	0.61	5, 160	.692	.019
Block X Sex	0.57	1, 160	.450	.004
Block X Age group X Sex	1.80	5, 160	.116	.053
Age group X Sex	**2.62**	**5, 160**	**< .05**	**.076**
Preparatory X Age group X Sex	0.84	5, 160	.523	.026
Trial Type X Age group X Sex	0.84	5, 160	.524	.026
CSI X Trial Type X Age group	0.84	5, 160	.527	.025
CSI X Trial Type X Sex	0.09	1, 160	.771	.001
CSI X Block X Age group	0.43	5, 160	.826	.013
CSI X Block X Sex	1.13	1, 160	.289	.007
CSI X Trial Type X Block	0.00	1, 160	.996	.000
Trial Type X Block X Age group	0.94	5, 160	.455	.029
Trial Type X Block X Sex	1.13	1, 160	.290	.007
CSI X Trial Type X Age group X Sex	**2.50**	**5, 160**	**.033**	**.072**
CSI X Block X Age group X Sex	1.74	5, 160	.130	.051
Trial Type X Block X Age group X Sex	0.36	5, 160	.878	.011
CSI X Trial Type X Block X Age group	1.69	5, 160	.140	.050
CSI X Trial Type X Block X Sex	0.78	1, 160	.378	.005
CSI X Trial Type X Block X Age group X Sex	1.19	5, 160	.317	.036

Note: This table does not include statistics regarding the main effects or interactions related to the covariates of PIQ and number of trials.

Table 7
Analysis of variance results for reaction times by age group, CSI, and trial type in males

Variable	F	df	p	η_p^2
Age group	**4.35**	**5, 70**	**<.01**	**.237**
CSI	**7.31**	**1, 70**	**< .01**	**.095**
Trial Type	1.56	1, 70	.216	.022
CSI X Age group	.95	5, 70	.455	.063
Trial Type X Age group	3.72	5, 70	.058	.050
CSI X Trial Type	.23	1, 70	.634	.014
CSI X Trial Type X Age group	.19	5, 70	.967	.013

Table 8

Analysis of variance results for reaction times by age group, CSI, and trial type in females

Variable	F	df	p	η_p^2
Age group	2.05	5, 88	.080	.104
CSI	.00	1, 88	.952	.000
Trial Type	.35	1, 88	.557	.004
CSI X Age group	**3.11**	**5, 88**	**< .05**	**.150**
Trial Type X Age group	**2.59**	**5, 88**	**< .05**	**.128**
CSI X Trial Type	.01	1, 88	.942	.000
CSI X Trial Type X Age group	**3.36**	**5, 88**	**< .01**	**.160**

Table 9
Pearson correlations between reaction time and error rate variables

	Short switch RT	Long switch RT	Short non-switch RT	Long non-switch RT
df	175	175	175	175
Short switch error	.42*	.44*	.41*	.45*
Long switch error	.35*	.34*	.31*	.39*
Short non-switch error	.31*	.32*	.29*	.37*
Long non-switch error	.29*	.31*	.29*	.39*

* $p < .001$

Table 10
Pearson correlations between self-reported behavior and switch cost variables

	Externalizing	Internalizing	Total Problems
df	174	174	174
Short switch – error rate	-.11	.07	-.01
Short non-switch – error rate	-.05	.14	.04
Long switch – error rate	.06	.16*	.11
Long non-switch – error rate	-.14	.01	-.06
Switch cost short – error rate	-.09	-.05	-.06
Switch cost long – error rate	.23 **	.19 *	.21 **
Short switch – RT	-.03	.12	.09
Short non-switch – RT	-.05	.11	.09
Long switch - RT	-.10	.07	-.01
Long non-switch - RT	-.08	.05	.00
Switch cost short - RT	.02	.06	.04
Switch cost long - RT	-.07	.04	-.03

* $p < .05$
** $p < .01$

Table 11
Hierarchical regression analyses: variables predicting error rate switch costs

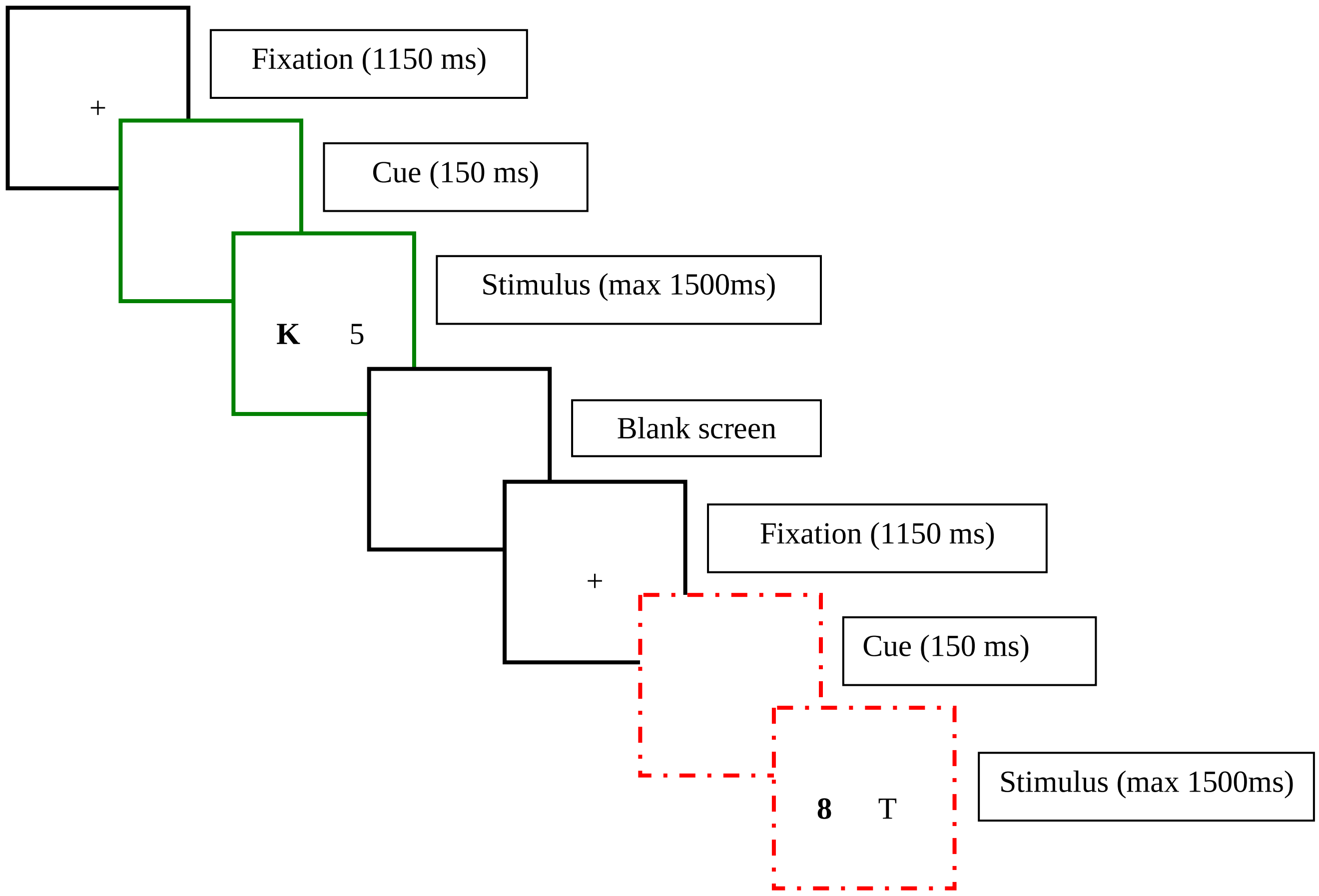
	Short CSI				Long CSI			
Step and variable	B	SE B	β		B	SE B	β	
Step 1								
Age	-.009	.003	-.249**		.000	.003	-.009	
Sex	.028	.021	.099	R^2 = .068**	-.012	.021	-.042	R^2 = .007
PIQ	.000	.001	-.012		-.001	.001	-.071	
Step 2								
Age	-.009	.003	-.245**		-.001	.003	-.022	
Sex	.025	.022	.087	ΔR^2 = .004	.000	.021	-.002	ΔR^2 = .046**
PIQ	.000	.001	-.020		.000	.001	-.042	
Externalizing	-.066	.079	-.064		.219	.077	.220**	
Step 3								
Age	-.009	.003	-.264**		.000	.003	.000	
Sex	.028	.022	.097	ΔR^2 = .005	-.004	.021	-.013	ΔR^2 = .007
PIQ	.000	.001	-.019		.000	.001	-.043	
Externalizing	-.016	.094	-.015		.162	.091	.163	
Internalizing	-.086	.088	-.088		.098	.085	.104	

* $p < .05$
** $p < .01$

Table 12
Hierarchical regression analyses: variables predicting reaction time switch costs

	Short CSI				Long CSI			
Step and variable	B	SE B	β		B	SE B	β	
Step 1								
Age	-7.300	1.440	-.367**	R^2 = .157**	-1.865	.915	-.158*	
Sex	-.346	11.291	-.002		-.984	7.176	-.010	R^2 = .025
PIQ	.617	.471	.094		-.025	.300	-.007	
Step 2								
Age	-7.353	1.444	-.369**		-1.829	.917	-.155*	
Sex	1.181	11.498	.007	ΔR^2 = .003	-2.045	7.305	-.022	ΔR^2 = .004
PIQ	.663	.476	.101		-.057	.303	-.015	
Externalizing	30.978	42.315	.053		-21.508	26.886	-.063	
Step 3								
Age	-7.568	1.495	-.380**		-1.662	.950	-.141	
Sex	2.093	11.632	.013		-2.750	7.387	-.029	
PIQ	.663	.477	.102	ΔR^2 = .002	-.057	.303	-.015	ΔR^2 = .003
Externalizing	46.519	50.431	.080		-33.526	32.028	-.098	
Internalizing	-26.591	46.717	-.049		20.563	29.670	.064	

* $p < .05$
** $p < .01$


Fixation (1150 ms)
+
Cue (150 ms)
Stimulus (max 1500ms)
K 5
Blank screen
Fixation (1150 ms)
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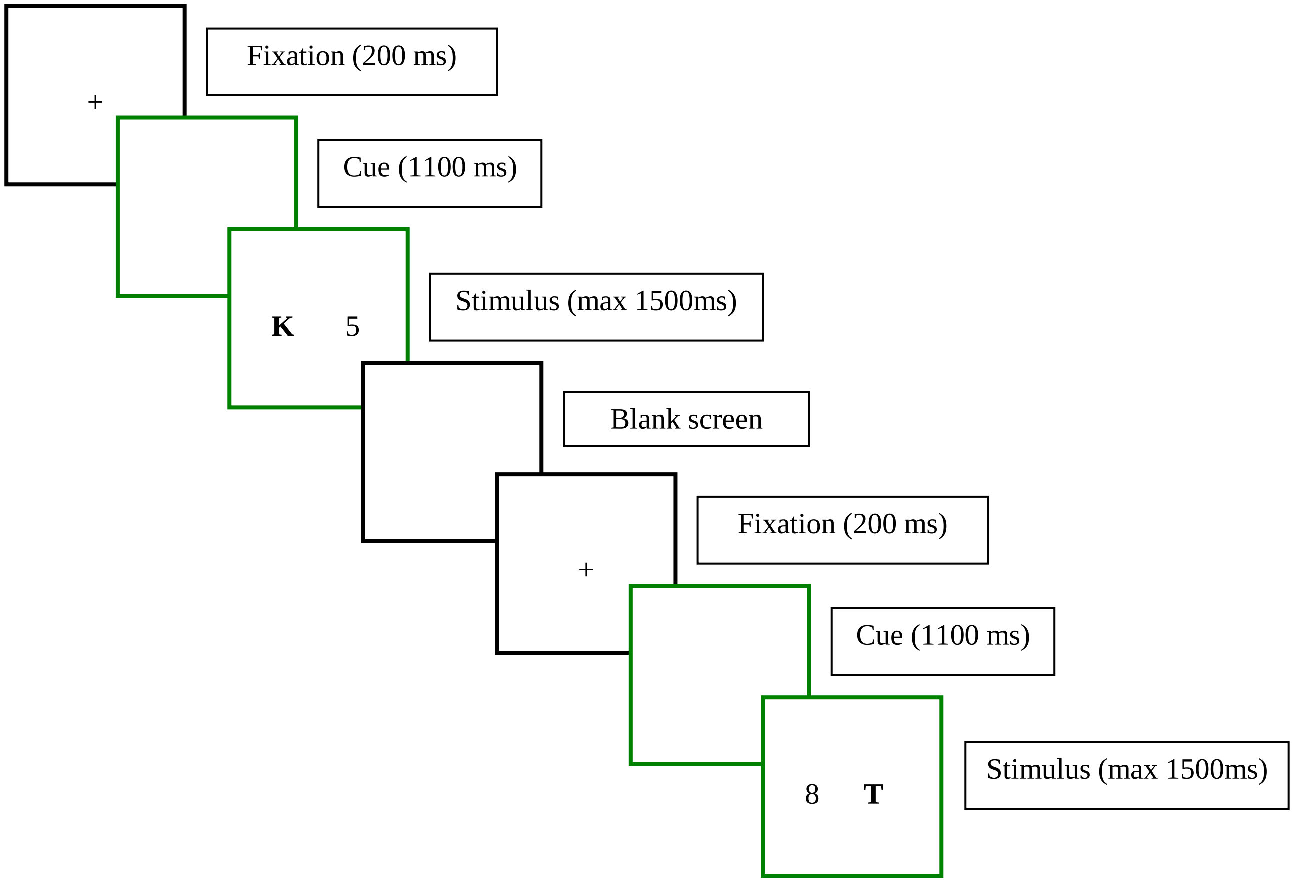
8 T

1a.



1b.

Figure 1. A diagram of the task switching paradigm depicting, (a) a short CSI switch trial and (b), a long CSI non-switch trial. The stimulus in bold print indicates the correct response.

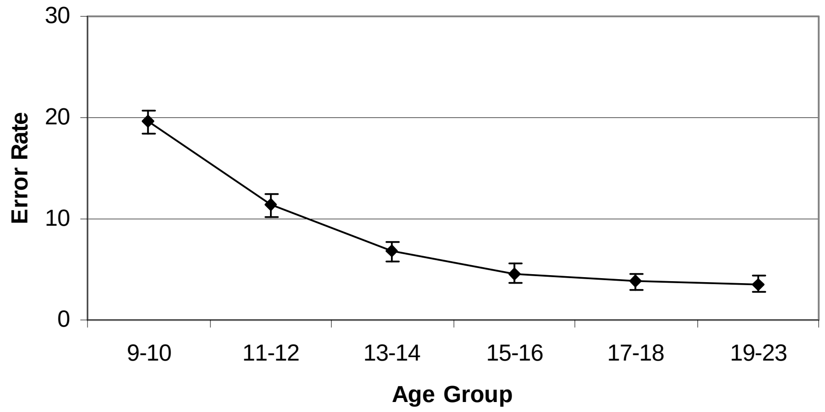


Figure 2. Estimated marginal mean error rates (± SE) for each age group.

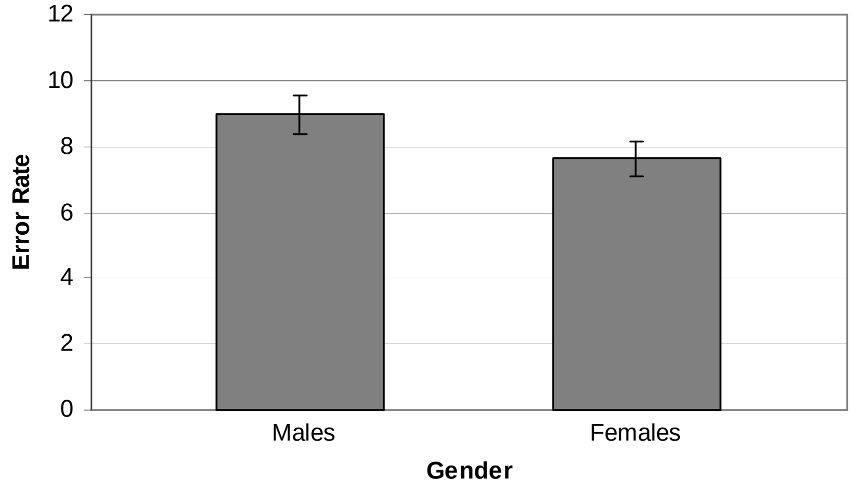


Figure 3. Estimated marginal mean error rates (± SE) for males and females.

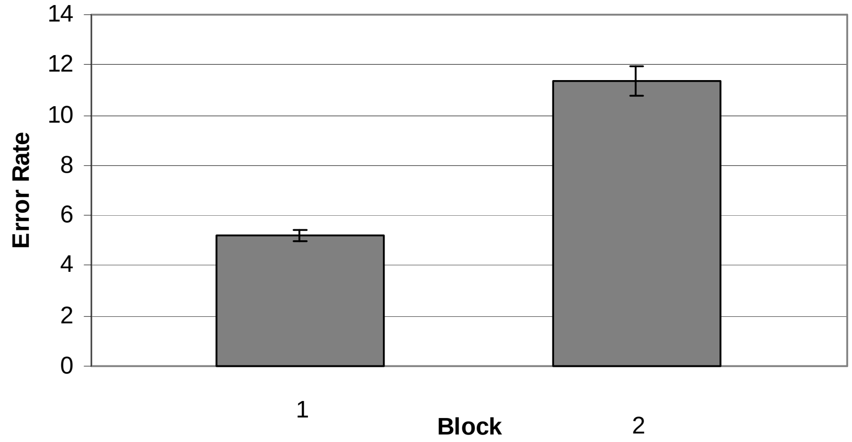


Figure 4. Estimated marginal mean error rates (± SE) for blocks 1 and 2.

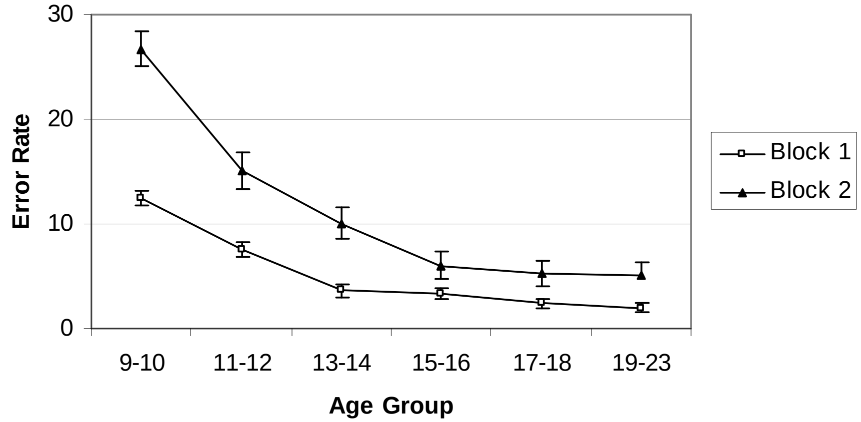
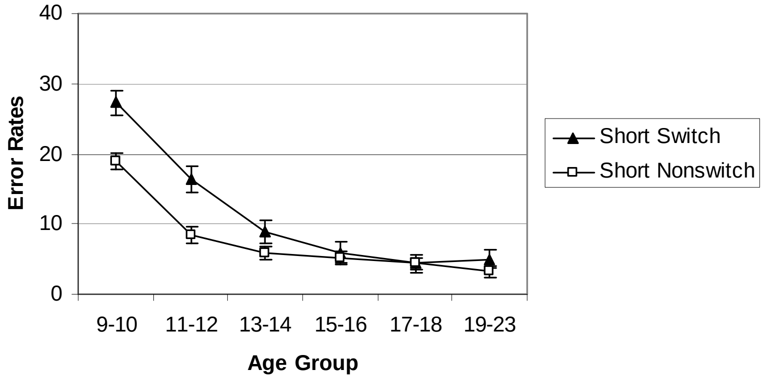
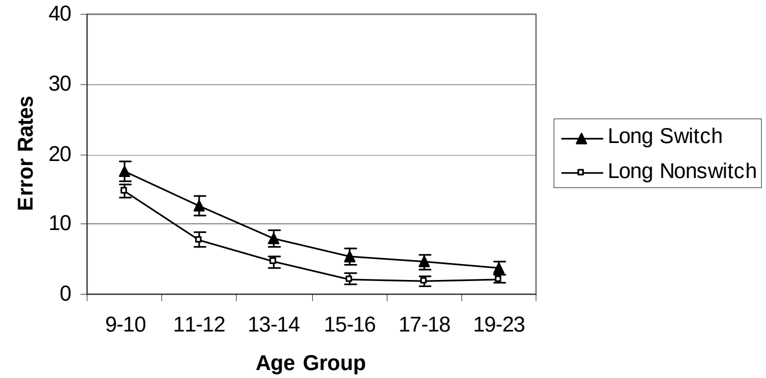


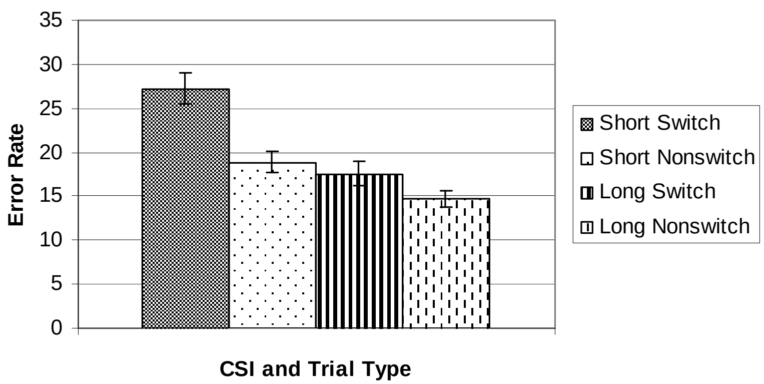
Figure 5. Estimated marginal mean error rates (± SE) for blocks 1 and 2 in each age group.



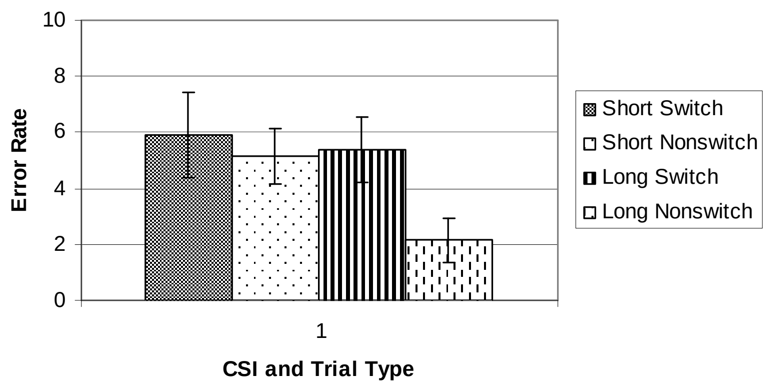
(a)



(b)



(c)



(d)

<u>Figure 6.</u> Estimated marginal mean error rates (± SE) for short (6a) and long (6b) CSI and trial types in each age group. Estimated marginal mean error rates (± SE) in each CSI and trial type in 9-10 year-olds (6c) and 15-16 year-olds (6d)

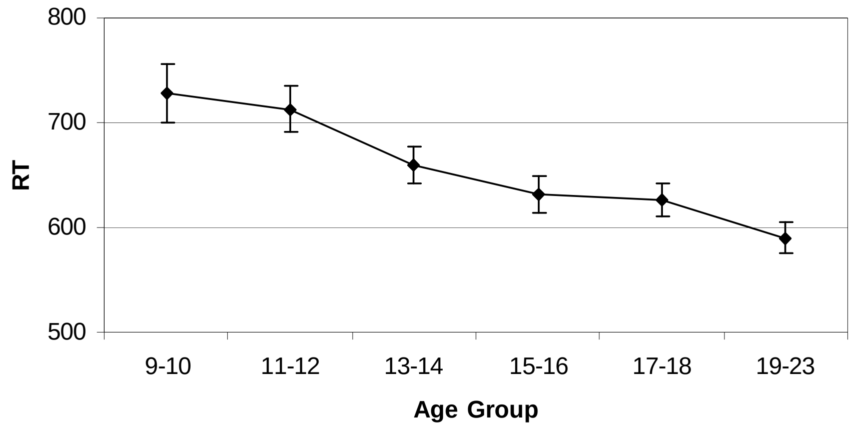


Figure 7. Estimated marginal mean reaction times (RT) (± SE) for each age group.

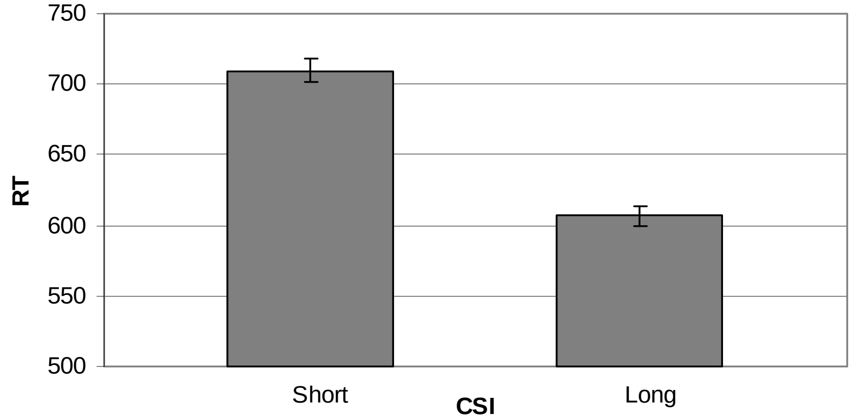


Figure 8. Estimated marginal mean reaction times (RT) (± SE) for each CSI.

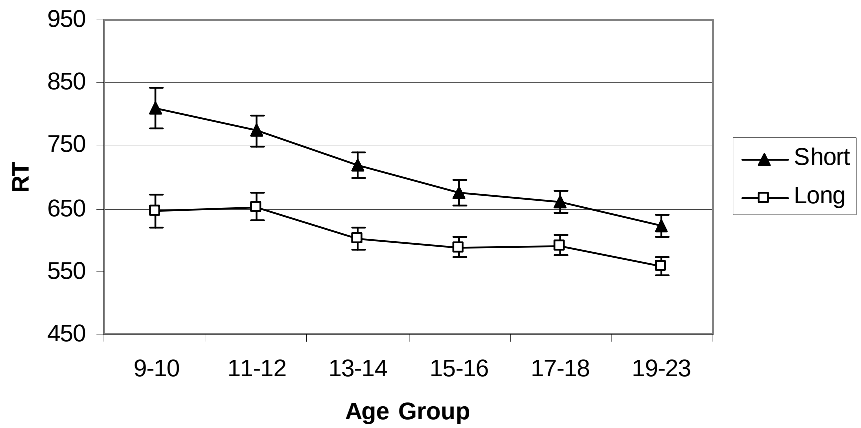


Figure 9. Estimated marginal mean reaction times (RT) (± SE) for each CSI trial within each age group.

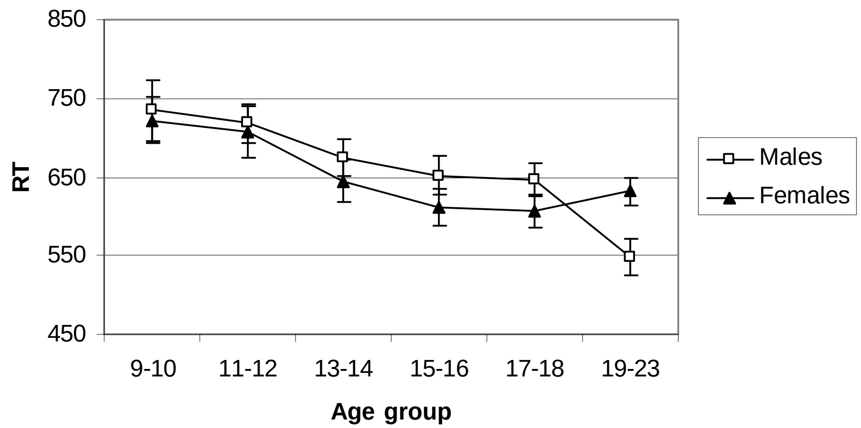


Figure 10. Estimated marginal mean reaction times (RT) (± SE) for males and females in each age group.

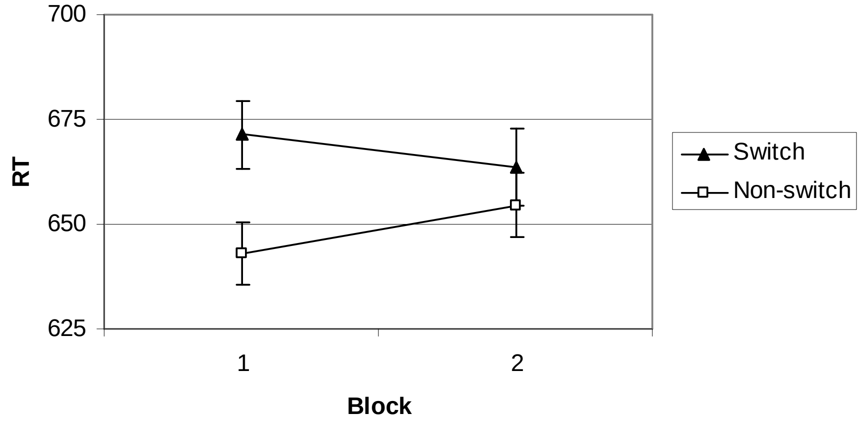


Figure 11. Estimated marginal mean reaction times (RT) (± SE) for each trial type in blocks 1 and 2.

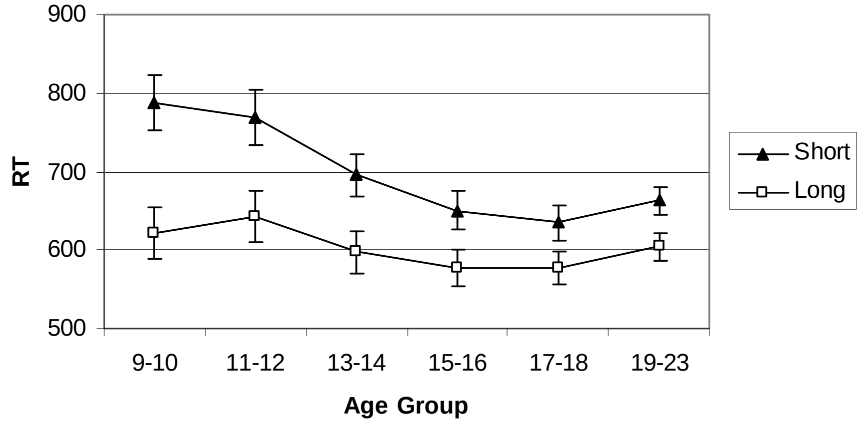


Figure 12. Estimated marginal mean reaction times (RT) (± SE) in females for each CSI trial within each age group.

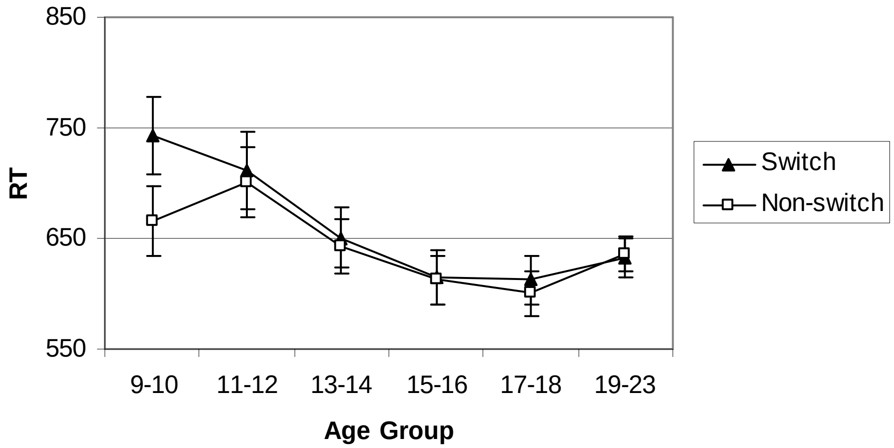
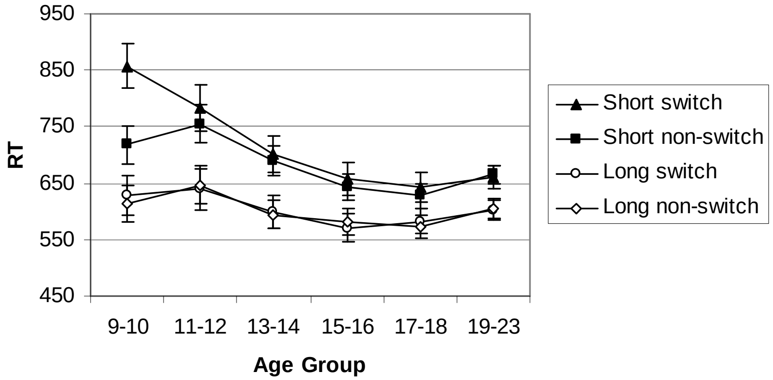
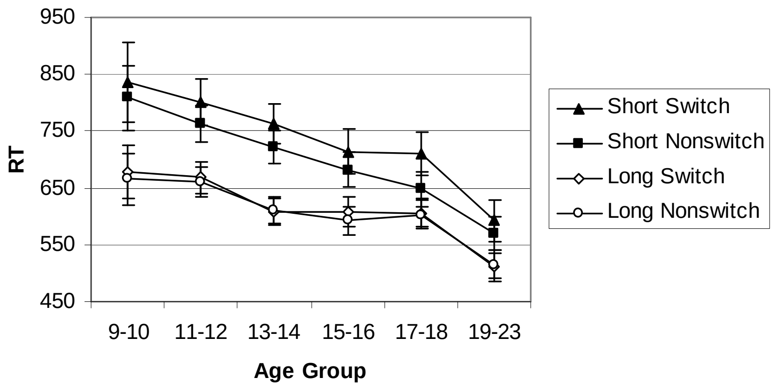


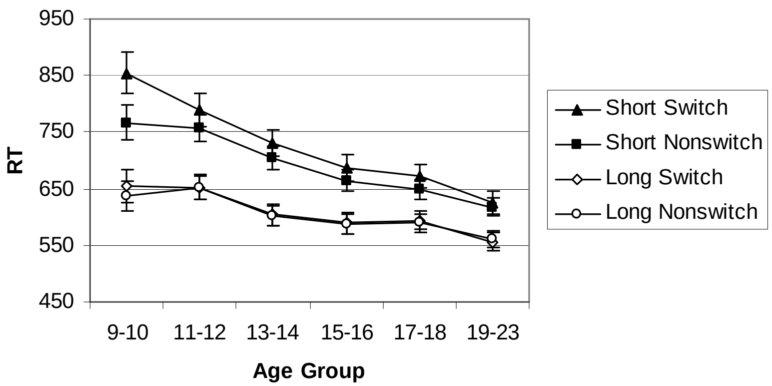
Figure 13. Estimated marginal mean reaction times (RT) (± SE) in females for each trial type within each age group.



(a)



(b)



(c)

Figure 14. Estimated marginal mean reaction times (RT) (± SE) in (a) females, (b) males, and (c) the whole sample for each trial type and CSI within each age group. Graphs of trial type and CSI in males and entire sample are included for comparison purposes.

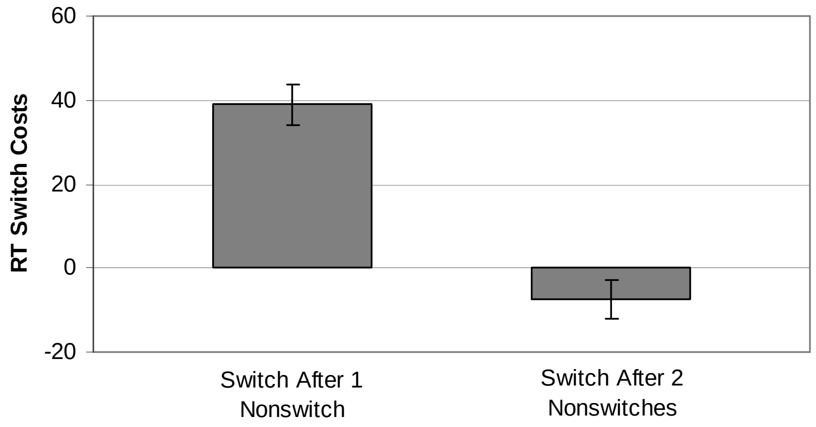


Figure 15. Estimated marginal mean error rates (± SE) on switch trials following one and two consecutive non-switch trials.

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