Functional Cognitive Changes in Developing Adolescents

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Abstract

The ability to accurately filter and suppress irrelevant information with competing thoughts and actions involves the attainment of higher cognitive functions through development. Specifically, the prefrontal cortex has been shown to play an important role in the progressive maturity of these executive functions, which are highly correlated to age-related development. To date, few studies have researched functional brain changes throughout adolescence. The efficiency in testing an individual’s ability to inhibit prepotent responses to irrelevant information, thoughts, and actions has been examined through the use of an emotional counting Stroop paradigm, and go/no-go assay. Response time and accuracy were compared between three cohorts, labeled as pre-adolescent (n = 45, mean age = 12 years), adolescent (n = 12, mean age = 17 years), and adult (n = 18, mean age = 22 years). It was found that during “go” trials, adolescents were significantly faster than individuals in the pre-adolescent group. During “no-go” trials, adolescents were significantly worse at inhibiting a response to irrelevant information. Within the Stroop paradigm, no significant differences were recorded between any of the cohorts. Performance levels between groups suggest that age differences are correlated to some cognitive functions; thus, contributing to existing literature regarding types of neural plasticity during the maturational process. Specifically, the ability to inhibit irrelevant information becomes more fully developed as an individual ages. Further research should include neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) in order to better relate functional changes to structural differences between groups.
Functional Cognitive Changes in Developing Adolescents

Adolescence is considered a period which involves many dramatic developmental transitions. Specifically, it is a time in which many regions of the brain undergo continual change and development into young adulthood, and involves the attainment of a broader set of skills and knowledge that is part of the cognitive functions acquired from maturation (Tapert, Caldwell & Burke, 2004; Dahl, 2004). It is marked by rapid increases in both physical and mental capabilities. Compared to younger children, adolescents are not only physically more advanced and mature, but they are also able to achieve developmental improvements in reaction time, reasoning abilities, immune function, and even the capacity to withstand cold, heat, injury, and physical stress (Dahl, 2004). In almost every measurable domain, this is a developmental period of heightened growth.

The question then arises of whether there are unique types of neural “plasticity” during puberty and adolescence, when a particular set of individual traits dealing with various cognitive processes becomes fully developed (Dahl & Spear, 2004). Currently, however, there is significantly less research that has focused on the cognitive changes that occur during this time period when compared to that of children and adults. It is therefore proposed that, as an individual develops throughout the maturational process, he/she will also progressively develop various cognitive abilities. The goal of the current study will investigate developmental differences in the ability of children, adolescents, and adults to effectively filter and suppress irrelevant information when participating in tasks with competing thoughts and actions; thus, contributing to the existing literature on this important topic.

Indeed, research has reported that many other neurobehavioral changes appear to be linked to this developmental period. These changes appear to have a significant effect on
cognitive processes, such as, affect recognition, working and emotional memory, the ability to filter and suppress irrelevant information, thoughts, and actions in favor of relevant ones, and the ability to maintain attention for sustained periods of time (Dahl, 2004; Wecker et al., 2000; Wurm et al., 2004). It is the goal of the current study to investigate the relationship between a few of these developmental processes in regards to the cognitive functional changes that occur in the maturing child, adolescent, and adult.

Barkley (1997a) postulated that the progressive development of inhibitory functioning is significantly related to the development of the prefrontal regions of the brain. More importantly, the development of executive functioning is dependent on the development of the behavioral inhibition processes. As such, it has been hypothesized by many researchers that younger children without developmental disability, or “normal” children, should be less efficient in behavioral inhibition compared to older normal children (Barkley, 1997b; Simpson, & Riggs, 2007; Jones et al., 2003). Behavioral inhibition, which is comprised of inhibition of prepotent responses, stopping of ongoing responses, and interference control, significantly contributes to the processing of other executive functions, such as working memory (verbal and non-verbal), self-regulation of affect, motivation, arousal, and the analysis and synthesis of information (see Brocki, & Bohlin, 2004 for review). Therefore, it would seem to follow that, since younger normal children should be less efficient in behavioral inhibition than older normal children, they will also be less efficient in the areas of executive functioning related to behavioral inhibition.

In regards to inhibition and the ability to filter and suppress irrelevant information, numerous experiments have shown that there is a significant increase in an individuals’ ability to inhibit responses as age increases (Williams et al. 1999). Specifically, Levin et al. (1991), upon using a go/no-go assay, found that the greatest improvement in response and missed responses
was between the youngest and middle cohorts, but little or no improvement in the oldest. Williams et al. (1999), upon using the stop-signal assay, were able to find that there was a significant development in the speed of inhibiting a prepotent response between three different cohorts, labeled as early childhood, mid-childhood, and young adult and senior groups. As with Levin et al. (1991), there was no significant advancement in the young adult and senior groups. As such, these findings, along with the support mentioned above in the current research, help support the hypothesis that as an individual ages throughout the developmental process, he/she will also progressively develop in executive function processes. As has been described by various research articles previously mentioned, such development seems to mostly occur around pubertal development and tends to plateau soon after (Barkley, 1997a).

The ability to filter and suppress irrelevant information, regulate responses, thoughts, and actions, and processing speed are functions involved within executive processing of the prefrontal cortex. Specifically, inhibitory control is integral to cognitive control as it allows individuals to internally process patterns of environmental stimuli to the degree that the stimuli can be used to exert control over various thoughts and behavioral responses. In other words, it is the ability to stop an inappropriate response or to ignore irrelevant information (Dagenbach, & Carr, 1994). However, there is little consensus among researchers on the exact definition of executive functions in adults as well as in children. This has come about because of the relatively recent development of research on executive functions in children. However, as mentioned previously, there is a lack of research that has focused on the cognitive changes that occur during this developmental period. Of the research that has been conducted, specific limitations have been noted. Primarily, there is no task or set of tasks that have been developed or agreed upon which are able to assess separate executive domains (Welsh, 2002). As a result,
it has been proposed by many, including the current research, that multiple tests assessing executive function will be more likely to yield a better understanding of its processes and development.

It would be relevant to further study tasks that recruit and rely on the prefrontal cortex as they would help to uncover the cognitive changes throughout maturation. The current research has attempted to implement paradigms related to prefrontal cortex development throughout the maturational process. The Stroop paradigm, along with the Go/NoGo task will be used in order to better estimate an individual’s ability to efficiently filter interference through competing thoughts and actions.

The Stroop (1935) paradigm has been used for decades as a common method that allows for the testing of an individual’s ability to maintain attention, while inhibiting an irrelevant response. In the emotional counting Stroop, a derivation of the original task, individuals are required to identify the number of words presented during each stimulus, while attempting to ignore the actual word shown. Emotional stimuli are used throughout the assay in order to test for the influence of emotional interference.

The go/no-go assay has also been used and shown as a reliable and accurate method for the investigation of inhibitory response (Gondo et al., 2000; Casey et al., 2005). Participants respond to both a “go” signal, while inhibiting a response to a “no-go” signal. With an abundance of go signals presented to the participants, it is necessary to suppress a response when a no-go signal is encountered, thereby allowing for the assessment of inhibitory control. Further investigations of these tasks, along with others, would allow for a greater understanding of their relation to neurobiological changes that underlie the cognitive maturation seen throughout adolescence. In fact, it has been suggested that the performance on such tasks, which coincide
with maturation, reflect structural development, and a refinement of the projections to and from the prefrontal and parietal cortices (Casey et al., 2005).

In an attempt to isolate cognitive processes that underlie a susceptibility to interference, Durston et al. (2002) used a go/no-go assay together with fMRI. It was found that inhibiting a response to a no-go trial was associated with increased activity in the ventral prefrontal cortex, which correlated with performance across age, with children making the most errors. Along with other research, this study supports that children tend to recruit a larger portion of the prefrontal region than adults when performing interference tasks (Casey et al., 2002). For instance, developmental studies involving DTI-based measures have been able to show a significant correlation with age in frontostriatal and posterior fiber tract connectivity (Liston et al., 2003).

In studies of primates, it was found that the ability to inhibit a response increased the firing of neurons located in the prefrontal cortex (see Gondo et al., 2000 for a review). Interestingly, however, PET scans between go/no-go conditions in humans have shown a right brain dominance in activation during response inhibition, or no-go trials (Gondo et al., 2000). Each of these findings correlates with age-related maturation of the prefrontal cortex. Specifically, the evidence that prior to pubertal onset, children are unable to perform at adult levels on these tasks that require cognitive maturation (Hooper et al., 2004).

In tasks involving variations of the Stroop (1935) paradigm, similar regions were activated, as previously predicted. For instance, the anterior cingulate cortex, which is part of the frontal lobe, has been shown to play a central role in interference and attention tasks (Bush et al., 1998). Casey et al. (2005) also reported that the Stroop task highly recruits regions of the prefrontal cortex. As such, it is proposed that as age increases, individuals will more likely be able to inhibit an irrelevant prepotent response, as well as respond more quickly and accurately.
Regarding the emotional stimuli of the Stroop paradigm, it has been found that older individuals have shown a higher level of resilience and competence in emotion regulation (Wurm et al., 2004). Adults are more likely to have developed emotional schemas, which may allow for a greater ability to process emotion-related stimuli.

Congruent with progressive changes in cognitive processes, brain structure matures concurrently in early childhood and throughout adolescence (Casey, Galvan, & Hare, 2005). As technological advances have been made in the ability to obtain images of brain development and maturation, more studies have used neuroimaging techniques such as magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), and diffusion tensor imaging (DTI). Each experimental technique is used to obtain distinct information, from structural images of the brain, to in vivo measures of brain activity, and even to providing data on brain connectivity in myelination and changes in white matter microstructure in vivo, respectively (Casey, Galvan, & Hare, 2005). However, it is important to note that each of these methodologies only provides an indirect relationship between brain function and structural changes within. As such, it is recognized by current research that it is extremely difficult to find a direct correlation between maturational changes and cognitive ability. The current study will attempt to better understand different cognitive abilities that positively change throughout the developmental process, and understand, when possible, at which point each change occurs. As such, subsequent correlations between cognitive development and brain development using research involving neuroimaging data would be important.

Of the limited research conducted, it has been found that there is a linear increase in prefrontal and parietal activation correlated with age (Scherf, Sweeney, & Luna, 2006). For example, Adleman et al. (2002), was able to show that the increase in activation in the parietal
lobe associated with improved cognitive performance develops by adolescence. However, increases in activation in the prefrontal cortex develop into adulthood. It is important to understand that the prefrontal cortex orchestrates high-level cognitive functions that support responsible adult behavior, such as the function of inhibitory control (Diamond, 1990). Based on post-mortem and pediatric neuroimaging studies, the prefrontal cortex has been shown to be one of the last brain regions to mature. Also, the most consistent MRI findings that have been published have shown that there is a lack of any significant change in the cerebral volume after five years of age, a significant decrease in cortical gray matter after 12 years of age, and an increase in white matter throughout childhood and into adulthood (Caviness et al., 1996; Giedd et al., 1996). In fact, it has been reported that overall brain size is usually developed to 90% its adult size by age six (Giedd et al., 1999). However, the gray and white matter subcomponents of the brain continue to change throughout adolescence (Giedd et al., 2004; Gotgay et al., 2004), while cortical gray matter in the frontal and parietal cortices does not significantly begin to decrease until puberty (Giedd et al., 1999). Furthermore, Sowell et al. (2001) showed that these gray matter changes are correlated to behavioral performance measures. The argument may be postulated, then, that the loss of gray matter that coincides with the increase of white matter underlie brain development and, therefore, cognitive development.

Significant to the progression of white matter in conjunction with the digression of gray matter is the development of the prefrontal cortex. Research based on the development of executive control and processes in adolescents has shown significant findings that the prefrontal cortex modulates these executive functions and its structural maturity coincides with age-related development throughout childhood and into adolescence (Luciana et al., 2005). A marked finding from studies in both humans and primates have shown that adolescence is characterized
by gray matter loss in numerous areas of the prefrontal cortex which allows for large synaptic pruning, and therefore, cognitive development (Giedd et al., 1999). In other words, neural connections used frequently are able to survive, while random connections are eliminated (van Baal et al., 2001). However, synaptic formation and elimination following this period of gray matter loss cannot currently be supported by imaging techniques because of the limited resolution obtained. Others have shown that white matter development, specifically myelination, which may play a role in the speed of cognitive processing, is also progressive throughout adolescent development (Caviness et al., 1996).

Gogtay et al. (2004) were able to perform a longitudinal MRI study, in which their results showed that cortical maturation parallels many developmental cognitive milestones. As many processes develop early in life and throughout childhood, higher-order association areas, such as the prefrontal and lateral temporal cortices mature last (Durston, & Casey, 2006). It would be extremely important to note, then, that with the development of these brain regions, an individual’s capacity to filter competing information and suppress inappropriate actions through cognitive control, significantly improves.

The current study will investigate the developmental differences in the ability of adolescents before, during, and after puberty into early adult life, to suppress inappropriate thoughts and actions if favor of a relevant response. It is hypothesized that, as an individual ages throughout the maturational process, significant improvements in reaction time, along with the ability to inhibit interfering stimuli will occur. A better understanding of the developmental processes that occur during puberty and its correlation to cognitive control will ensue. It is hopeful that the information gathered may lead to a greater understanding of learning
development and maturational differences throughout puberty in adolescence and adult life significant to cognitive development.

Method

Participants

Seventy-three subjects, separated into three distinct cohorts labeled as pre-adolescents, adolescents, and adults, participated in the current study. The pre-adolescence group consisted of 45 individuals whom were randomly selected from a sixth grade class at St. John the Baptist Middle School in Draper, Utah. At the time of study, each participant was approximately 12 years of age in his/her sixth grade year in school. The adolescent group consisted of twelve (12) students whom were approximately 17 years of age at the time of study. Each participant within this group was found to be within his/her junior year of high school and was chosen from a chemistry class at Juan Diego High School. The adult cohort consisted of eighteen (18) students beyond their second year of college at the time of the study, whom were chosen from a cognitive neuroscience course at Westminster College. Race and gender among the participants in each cohort accurately reflect middle-class demographics in Salt Lake City, Utah. The data collection and results of each individual were included in the study, and were only excluded upon the request of the participant and/or the discontinuation of the participant in the study.

Prior to the onset of the study, parent consent was obtained for all participants under the age of 18 (see Appendix A). For participants of legal age (over 18), verbal assent was obtained and results were discussed as a group soon after (see Appendix B). Laboratory credit was given to those who participated from the adult cohort. Only upon acceptance to the terms and conditions outlined in the consent forms, or through verbal assent, were the subjects able to
participate in the proposed study. Before the beginning and throughout each experimental assay, participants were reminded that they could discontinue participation at any time, if desired.

In order to maintain confidentiality, each participant was provided with a random number within his/her cohort in order that no names could be disclosed or associated with the results. The investigator, along with any individuals associated with the experiments, was unaware as to the name of the participant, and never, at any time, obtained personal or identifiable information of the participant. The number with which each participant was provided was consistent for that individual throughout the testing process. Within the collection of data, only the participant’s number was shown with his/her results so as not to be able to identify or separate any individual accordingly.

Procedure

The current experiment took place in two distinct locations. The pre-adolescent and adolescent groups participated in the study within a computer lab at Juan Diego High School. Students were staggered throughout the room during the testing process in order that any external distractions would be controlled as much as possible. Within the pre-adolescent group, it was necessary to divide the participants into five separate groups, distinguished by their class period at the time they participated in the study. The adult cohort participated in the study in the psychology laboratory at Westminster College with the same experimental assays as the other cohorts. In order to account for any confounding stimuli, participants were divided into groups of four individuals.

Measures

In order to test for an individual’s ability to filter and suppress irrelevant information, thoughts, and actions in favor of relevant ones, a computerized go/no-go task based on the go/no-
go paradigm was used (Iaboni et al., 1995). This task is a widely used assay in clinical and
cognitive neuroscience, including brain imaging studies (Rush et al., 2006). For this task,
participants were placed in front of a computer screen where they viewed a series of letters (20% of which were Xs) presented one by one for 120 trials. Each letter was presented for approximately 250 ms, with a 1000 ms interstimulus interval. Participants pressed the space bar with their dominant hand in response to every letter except X, and were asked to withhold a response when they saw an X. The ability of an individual to inhibit response when an X appears was measured within the age group and across cohorts.

To further test for an individual’s ability to inhibit irrelevant information through competing thoughts and actions, a variant of the Stroop paradigm, known as the emotional counting Stroop, was used. The emotional counting Stroop has 64 trials in which sets of 1-4 identical words appeared on the computer screen. Participants were asked to identify the number of words on the screen using the number pad on the keyboard. Words were either neutral (e.g., "cat" written four times), compatible number words (e.g., "three" written three times), incompatible number words (e.g., "two" written four times), or emotionally charged words (e.g., "sad" written three times). Reaction times have been compared between conditions to ascertain whether certain stimuli provoke relatively shorter or longer reaction times.

Results

Results of the Go/No-Go assay were calculated as follows:

Efficiency in testing an individual’s ability to filter and suppress irrelevant information, thoughts, and actions, in favor of relevant ones is examined by requiring the subject to respond to “go” and “no-go” cues presented on the computer screen, and through the mean reaction times
(RT) of each. In order to calculate the differences between cohorts, the difference in mean RT of “go” and “no-go” cues was compared between cohorts. Differences in “no-go” trials were calculated by the mean number of incorrect responses between cohorts. An alpha level of .05 was used for all statistical tests.

Results of the Go/No-go assay are summarized in Table 1.

It was hypothesized that as an individual ages throughout the developmental process, it will be more likely that he/she will be able to filter and suppress irrelevant information more accurately. A one-way analysis of variance (ANOVA) was conducted on participants’ reaction time (RT) during “go” trials. The analysis was significant, F(2, 60) = 3.73, p<.05. Post hoc paired comparisons were made using Tukey’s HSD test with alpha set at .05. The mean RT of “go” trials in the adolescent group was significantly faster (M = 389.07, SD = 65.18) than participants found within the pre-adolescent (M = 444.35, SD = 66.62). No other significant differences were found between any group and the adult group (M = 424.67, SD = 38.86).

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A one-way ANOVA was calculated on participants’ reaction time during “no-go” trials. The analysis was significant, F(2, 58) = 4.868, p<.05. A Tukey HSD test revealed that participants within the adolescent group (M = 308.75, SD = 34.39) were significantly faster than the pre-adolescent group (M = 360.99, SD = 54.20). No significant differences were found with the adult group (M = 354.83, SD = 43.59). However, when a one-way ANOVA was calculated for the number of times a “no-go” trial was counted, significance was found, F(2, 58) = 5.26,
Further testing using a Tukey HSD revealed that the both the pre-adolescent group (M = 7.06, SD = 4.04) and the adult group (M = 5.71, SD = 2.81) were significantly more able to withhold a response in the presence of a “no-go” trial compared to the adolescent group (M = 11.00, SD = 5.97).

Results of the Emotional Counting Stroop assay were calculated as follows:

Efficiency in testing an individual’s ability to filter and suppress irrelevant information, thoughts, and actions, in favor of relevant ones is examined by requiring the subject to respond to various stimuli labeled as neutral (e.g., "cat" written four times), compatible number words (e.g., "three" written three times), incompatible number words (e.g., "two" written four times), or emotionally charged words (e.g., "sad" written three times). Reaction times between cohorts have been compared in order to ascertain whether certain conditions provoke relatively shorter or longer reaction times. An alpha level of .05 was used for all statistical tests.

Results of the Emotional Counting Stroop assay are summarized in Table 1.

It was hypothesized that as an individual advances throughout the developmental process, it will be more likely that he/she will be able to filter and suppress irrelevant information more accurately. Specifically, with the emotional counting stroop assay, neutral stimuli should not affect the performance of the participants within each cohort, but rather establish a mean reaction time for comparison with the other stimuli. Compatible number, incompatible number, and emotional stimuli were separately analyzed against neutral stimuli and the differences them were
analyzed between groups in order to calculate a stroop effect. It was hypothesized that an individual further along in the developmental process will filter said information more quickly, and therefore, will have a smaller stroop effect.

A one-way analysis of variance (ANOVA) was calculated on the difference in participants’ reaction times during compatible and incompatible number stimuli when compared to neutral stimuli. The analysis showed no significance, F(2, 48) = 3.013, p>.05. No significant differences were found between the pre-adolescent group (M = 114.05, SD = 104.14), the adolescent group (M = 112.72, SD = 80.46), and the adult group (M = 25.45, SD = 130.71).

A one-way ANOVA was calculated on the difference in participants’ reaction times during positive emotional stimuli when compared to neutral stimuli. The analysis was not significant, F(2, 48) = .941, p>.05. No significant differences were found between the pre-adolescent group (M = -5.87, SD = 70.11), the adolescent group (M = -21.20, SD = 44.40), and the adult group (M = 28.15, SD = 149.64).

A one-way ANOVA was calculated on the difference in participants’ reaction times during negative emotional stimuli when compared with neutral stimuli. The analysis was not significant, F(2, 48) = .395, p>.05. No significant differences were found between the pre-
adolescent group (M = -4.93, SD = 76.19), the adolescent group (M = -3.15, SD = 58.29), and the adult group (M = -44.62, SD = 256.18).

Discussion

The susceptibility of an individual to interference of competing thoughts and actions progressively declines as age increases, more particularly around pubertal maturation (Casey et al., 2005; Tapert et al., 2004; and, Dahl, 2004). It was hypothesized that as an individual ages, it is more likely that he/she will increase in cognitive control. This attainment of a broader set of functional skills is established through a greater refinement of neural substrates found within the prefrontal cortex. In order to obtain a better understanding of the differences in adolescents, when compared to children and adults, the ability of separate cohorts in inhibition tasks was analyzed.

It is difficult to specifically pinpoint the processes that contribute to cognitive development, especially with research that only shows significant results in behavioral analyses. Although the current study investigated three separate cohorts on the same executive functions, only behavioral differences based on the data received can be made. However, as Amso and Casey (2006) speculated, each of those cohorts may have arrived at their results through very different neural pathways.

Within the go/no-go assay, it was proposed that as age increased, reaction times would also significantly improve. During “go” trials, it was found that there was a significant decrease
in reaction time in the adolescent group, when compared to the pre-adolescent group. In other words, with the onset of puberty, individuals were able to improve reaction times when responding to normal trials. This finding is consistent with Luciana et al. (2006) in that processing speed is highly correlated with age-related declines of gray matter and subsequent progression of white matter. Specifically, white matter is indicative of myelination of the axon sheath of neurons. With greater myelination, processing speed will increase. However, no significant differences were found with the adult group related to any other group. No inference regarding the adult group will be made at this time.

It was postulated that adolescents and adults would have a greater ability to inhibit responses compared to younger individuals. However, upon calculating the incorrect responses made in “no-go” trials, it was found that adolescents actually had a significantly greater difficulty to withhold a response in the presence of interfering stimuli. Contrary to much research (Barkley, 1997b; Jones, 2003), both children and adults were able to inhibit responses more accurately and less frequently than adolescents. It is important to note, however, that mean reaction time for adolescents was also significantly greater in “no-go” trials when compared to children. One explanation regarding this phenomenon might include the inability to effectively inhibit a response until a developmental period within adolescence might be reached. Although it is difficult, it would be important for future research to longitudinally measure developmental differences within the same cohort. By so doing, the ability to specifically pinpoint a direct relationship between development and function would be attained.

Within the emotional counting Stroop paradigm that was implemented in the current study, it was expected that differences in mean reaction times between the neutral stimuli and the variable stimuli would decrease as an individual ages. In other words, the stroop effect would be
less likely to occur as an individual ages. During incompatible and compatible number stimuli, no significant differences were found between any groups. It would be important to note, however, that adults were affected much less when compared to both children and adolescents. The inability to achieve a significant finding may be due to a small sample size in the adult cohort. Clarification of these findings might implement a more congruent sample size across each cohort.

When encountered with positive emotional stimuli, there were no significant differences in stroop effect within any of the groups. Although the adult group was more greatly affected by the stroop effect in that they were slower with positive stimuli compared to neutral stimuli, it was not significantly so. Differences in participants’ reaction times in negative emotional stimuli compared to neutral stimuli showed no significant difference between any of the groups as well. Similarly, however, it was found that the adult group was more greatly affected by the stroop effect. The difference between negative stimuli and neutral stimuli showed that adults were able to more quickly respond when negative words appeared. However, the differences were not significant.

Durston and Casey (2006) concluded that it is important to distinguish between the differences in development with learning, and the neural changes that take place with development. It is partially done through functional imaging studies, as well as equating performance between groups. The current study lacks any definite imaging results related to the assays researched. However, some neural developmental conclusions may be made through inferences as the three cohorts were compared separately. It might be that the processes required to efficiently perform in the go/no-go task had not fully developed in the pre-adolescent group, but were by the adolescent group. With the stroop task, the processes required may have been
developed prior to the onset of physical maturation, even in the pre-adolescent group; hence, the lack of significant findings between the groups.

A weakness of the current study is that we did not obtain a cohort that would significantly differ from the adolescent group. Although the age of 22 is usually found to be a period after pubertal processes have slowed down significantly, it would have been important to obtain participants beyond that age as well to better represent an “adult” cohort. Given this information, along with the fact that the groups themselves significantly varied in participant number, the results obtained in the current study might not accurately reflect differences in adolescents from adults. The adult cohort, with a mean age of 22, might still be too young to reliably conclude any significant differences between the groups. As van Baal et al. (2001) found in maturation, it may be that the adult cohort was still in the process of undergoing the progressive elimination of excess synapses while obtaining a higher white matter volume with myelination of the prefrontal cortex. As such, the differences found, when speaking about the post-adolescent group compared to the others, might really be a reflection of the differences in the groups and participants themselves, and not actually an accurate representation of an adult cohort in ability with the Stroop effect.

Due to a lack of resources and time, additional tests assessing other cognitive processes were unable to be conducted. This is a fault of the current research since only conclusions regarding those processes can be made. Speaking of adolescence as a whole (time period), it is difficult to make conclusions on its significant increase in cognitive control with only the two assays used, both of which assess the ability to filter and suppress irrelevant information. It would be important for future research to create and assign other cognitive tasks which would implement different higher cognitive function. Some of the assays used might include the n-
back for working memory, affect recognition assays (Ekman and Friesen, 1975), and the
Attentional Network Test (ANT) for sustained attention and orienting.

The general issue of the ability to inhibit a response when competing with interference
remains an important issue in the field of cognitive development. It would be important to
continue to further study the relationship between cognitive function with structural changes that
occur throughout the developmental process. Such contributions to this field of research, along
with the results obtained in the present study, would help to increase the development of this
field of study.
References


# TABLE 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Go Mean RT</th>
<th>NoGo Mean RT</th>
<th>NoGo CountNUM</th>
<th>Number Stroop Effect</th>
<th>Positive Emotion Stroop Effect</th>
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<td>Std. Deviation</td>
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<td>131.48231</td>
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### One-Way ANOVA

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<th>Mean Square</th>
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<th>Sig.</th>
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<tr>
<td>Go Mean RT</td>
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<td>14050.076</td>
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<td>226138.709</td>
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<td>NoGo Mean RT</td>
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<td></td>
<td></td>
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<tr>
<td>Between Groups</td>
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<td>11696.402</td>
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<tr>
<td>Within Groups</td>
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<td>2402.647</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
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<td>Positive Emotion Stroop Effect</td>
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<tr>
<td>negstroop</td>
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</table>
Graph Captions

Graph 1: Mean reaction time of “go” trials

Graph 2: Mean reaction time of “no-go” trials

Graph 3: Mean number incorrect of “no-go” count

Graph 4: Mean difference in reaction time in number stroop effect

Graph 5: Mean difference in reaction time in positive emotion stroop effect

Graph 6: Mean difference in reaction time in negative emotion stroop effect
Graph 1

"Go" Trial Mean RT

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Mean RT (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-adolescent</td>
<td>444.35</td>
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<tr>
<td>Adolescent</td>
<td>389.07</td>
</tr>
<tr>
<td>Adult</td>
<td>424.67</td>
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</tbody>
</table>
Graph 2

"No-Go" Trial Mean RT

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Mean RT (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-adolescent</td>
<td>360.99</td>
</tr>
<tr>
<td>Adolescent</td>
<td>308.75</td>
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<tr>
<td>Adult</td>
<td>354.83</td>
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</table>
Graph 3

No-Go Count by Cohort

Mean Incorrect

Pre-adolescent: 7
Adolescent: 11
Adult: 6
Graph 4

Number Stroop

Mean RT (ms)

0.00
25.00
50.00
75.00
100.00

Pre-adolescent
Adolescent
Adult

114.05
112.72
25.44
Graph 5

Positive Emotion Stroop

Mean RT (ms)

-5.87
-21.20
28.15

Pre-adolescent
Adolescent
Adult
Graph 6

Negative Emotion Stroop

Mean RT (ms)

Pre-adolescent
Adolescent
Adult

-4.93
-3.15
-44.62
APPENDIX A-1

Westminster College
Institutional Review Board (IRB)

For the Protection of Human Subjects

Parent/Guardian Permission Form
Research Involving Minors (under age 18)

Dear Parent/Guardian:

Your child has been invited to participate in a research study conducted by a small group of psychology researchers from Westminster College. The study in which your child has been invited to participate will be proctored by Brandon Beck, an undergraduate at Westminster College, working under the direction and guidance of Dr. Lesa Ellis from the Psychology Department. This form contains important information that both your child, as the potential participant, and yourself, as their parent/guardian, will want to read through carefully in order to make an informed decision. Thank you for your time and considered participation in this study.

Before agreeing to allow your child to participate in this study, it is important that the following explanation of the proposed procedures be read and understood. It describes the purpose, procedures, benefits and risks of the study. It also describes alternative procedures available and the right to withdraw from the study at any time. It is important to understand that no guarantee or assurance can be made as to the results. It is also understood that refusal to participate in this study will not result in negative consequences for you or your child.

“I, ____________________________, agree to allow my child ______________________ to participate in a research study, the purpose of which is to better understand the relationship between cognitive development/maturational and learning processes throughout adolescence. The processes that my child will participate in will be relevant in their ability to: 1. Filter and suppress irrelevant information, thoughts, and actions in favor of relevant ones; 2. Remember and recall information previously provided to them; 3. Maintain attention; and, 4. Interpret emotion in facial expressions. Also, in order to consider hormonal differences in results, my child will be given a short questionnaire in which he/she will answer questions regarding where he/she now finds him/herself in the maturational process and the possible changes that are happening to his/her body (see copy of Attachment for details).

“In addition to the questionnaire, my child will be asked to participate in a series of four computer games that are designed to measure his/her cognitive development/maturational v. his/her learning ability as previously discussed in the above paragraph.

“There are no foreseeable side effects/risks associated with this project. However, as in all research, some side effects/risks may be unforeseeable. It is hopeful that the information gathered may lead to a greater understanding of learning development and maturational differences throughout puberty in adolescence and adult life significant to cognitive
development. I understand, however, that neither my child nor I can be guaranteed to personally receive any benefits from participation in this study beyond those that are educational in nature.

“It is understood that my child will be allowed to discontinue his/her participation in the study at any time by informing the researcher that he/she wishes to stop. He/she does not have to answer any questions with which he/she feels uncomfortable, nor participate in any computer game(s) if he/she finds them too difficult or boring.”

The contact person, should your child wish to withdraw from the study or should you or your child have questions about the study, is:

Dr. Lesa Ellis  
Professor of Psychology  
Westminster College  
(801) 832-2425

If you have any questions regarding your child’s rights as a research participant, please contact:

Dr. Jean Dyer  
IRB Chair  
Westminster College  
(801) 832-2168

I understand that all personally identifiable study data will be kept confidential. However, the results of this study may be made available to you upon request or used in formal publications or presentations.

If the risks and benefits associated with this study have been explained to your satisfaction, as well as your child’s rights as a research participant, and you wish to allow your child to participate, please sign and date this form where indicated. You will be provided a copy of this form for your records.

_________________________________________  ________________  
Signature of Parent/Guardian  Date

_________________________________________  ________________  
Signature of Witness  Date

_________________________________________  ________________  
Signature of Primary Investigator  Date
APPENDIX A-2

Westminster College
Institutional Review Board (IRB)
For the Protection of Human Subjects

Assent Form for Minors (under age 18)

You have been asked to participate in a research study called:

**Functional Changes in Cognition in the Developing Child, Adolescent, and Adult**

The study has been explained to you by: Brandon Beck

You don’t have to participate if you don’t want to, and you can quit at any time. All of your information will be kept private.

If you want to participate, please sign your name below and write the date next to your name.

____________________________________________  __________________
Signature of Participant  Date

____________________________________________  __________________
Signature of Witness  Date

____________________________________________  __________________
Signature of Investigator  Date
APPENDIX A-3

PROTOCOL – MIDDLE SCHOOL/HIGH SCHOOL DATA COLLECTION
St. John the Baptist Middle School/Juan Diego High School
300 East 11800 South

1. Go to the assigned classroom and introduce yourself to the instructor.

2. The students who have the consent forms signed and assent to the study will be selected to go to pre-designated room to begin the study.

3. After the students are seated in the newly assigned room, the following announcement will be read:

“My name is Brandon Beck and I am a student from Westminster College. We are hoping to gather some information from you that will give us a better understanding about brain development. Neuroscientists have recently discovered that there are important brain changes happening during the early teen years and into adult life. The questionnaire and computer games you will be completing today will help us understand those changes.

You will be filling out one questionnaire, which will help us understand the body changes that you have experienced. There are no right or wrong answers on any of the questions. People answer the questions in many different ways. Your name will not be on your questionnaire, and no one will know who you are when they look at the responses. Try to answer all the questions honestly, but you don’t have to answer anything you don’t want to answer. You can also quit filling out the questionnaires at any time if you want to, but we would really appreciate it if you answered everything. We don’t have much time, so you’ll need to work as quickly as you can. When you’re filling out the questionnaires, if you have any questions just raise your hand and I’ll come and help you.

After you are done filling out the questionnaire, raise your hand and I’ll know that you are ready to begin the computerized games. There are a total of four games that you will be able to play that will help us understand and measure some of those brain changes and how they may affect function. However, since some games may take a little time, you will only finish two today and two next week when I come back. The games will take about 45 minutes to play today and 45 minutes next week. If you have questions about the games any time before, during, or after, don’t worry about raising your hand and asking me. Also, remember that you may stop playing the games at any time that you want. You do not have to finish if you feel uncomfortable for any reason, or simply do not wish to continue. However, we would really appreciate it if you could try your best and finish the games.

Does anyone have any questions so far? Thank you so much for participating. Please raise your hand when you are finished with the games and you will then be able to go back to class.
Before agreeing to participate in this study, it is important that the following explanation of the proposed procedures be read and understood. It describes the purpose, procedures, benefits and risks of the study. It also describes alternative procedures available and the right to withdraw from the study at any time. It is important to understand that no guarantee or assurance can be made as to the results. See Below.

You have been invited to participate in a research study, the purpose of which to gain a better understanding of the relationship between cognitive development/maturation and learning processes throughout adolescence and into adulthood.

The study procedure(s) that you have been invited to participate in will be relevant in your ability to: 1. Filter and suppress irrelevant information, thoughts, and actions in favor of relevant ones; 2. Remember and recall information previously provided to you; 3. Maintain attention; and, 4. Interpret emotion in facial expressions.

The duration of the study is expected to take place in two separate segments on two separate days, each of which will take approximately 45 minutes of your time. You will be notified of any significant variance from the stated duration of the study.

There are no foreseeable side effects/risks associated with this project. However, as in all research, some side effects/risks may be unforeseeable. It is hopeful that the information gathered may lead to a greater understanding of learning development and maturational differences throughout puberty in adolescence and adult life significant to cognitive development.

Your participation in this study is entirely voluntary, and you may withdraw from the study any time you wish without any penalty to you.

If you have any questions about this study or wish to withdraw, please contact:

Dr. Lesa Ellis
Professor of Psychology
Westminster College
(801) 832-2425

If you have any questions regarding your rights as a research participant, please contact:
All personally identifiable study data will be kept confidential. However, the results of this study may be made available to you upon request or used in formal publications or presentations.

If you feel that you have received a satisfactory explanation as to the risks and benefits of this study as well as your rights as a research participant and you would like to participate, please sign and date below. You will be given a copy of this form for your records.

____________________________________________  __________________
Signature of Subject                     Date

____________________________________________  __________________
Signature of Investigator                  Date