Developing Interactions between Executive Function and Emotion during Adolescence

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Abstract

Adolescence is reputed to be a time of heightened emotionality and limited impulse control. Furthermore, emotion is frequently cited as the instigator of impulsive actions within this developmental period. That is, adolescents' powerful emotions may disrupt efforts to self-regulate and lead to impulsive actions that do not, in fact, serve the individual's long-term goals. Additionally, poor decision-making during this age range frequently has serious negative consequences. Understanding the cognitive and neurobiological mechanisms underlying the developing relationship between emotion and cognitive control may ultimately help us encourage teens to avoid potentially dangerous decisions and actions. To this end, this dissertation presents four studies aimed at better understanding the influence of emotion on higher-level cognition and self-regulation during adolescence. The first study introduces a task that requires participants to ignore emotional images while exercising inhibitory motor control (a go-nogo task). The second study uses functional magnetic resonance imaging (fMRI) to explore age differences in brain activation during performance of the emotional-distraction go-nogo task introduced in the first study. The third study extends the emotional distraction paradigm to a second form of higher-level cognition by using emotional images as backgrounds in an n-back working memory task. The fourth study examines the influence of early institutional care and BDNF genotype on performance of the emotional-distraction go-nogo task. Together these studies inform us regarding developmental changes in the interface between emotion and cognition during adolescence.

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Social and cognitive demands change dramatically during adolescence as individuals become more independent from their caregivers, strive to establish a more mature self-concept, and move into a highly nuanced social context dominated by peers. During these transitional years, adolescents increasingly must learn to self-regulate and to make decisions in the absence of adult supervision. This task is made more difficult by motivational and affective changes that accompany the onset of puberty (Arnett, 1999). Additionally, regulatory cognitive capacities necessary for overriding intense emotions and desires develop slowly, as do their neural correlates, not reaching adult levels until a decade or so after pubertal changes begin (Spear, 2000a). Cognitive and neuroimaging approaches have begun to provide insight into the mechanisms underlying the developing relationship between emotion and cognitive control as it evolves across adolescence.

Both the processing of emotional information and the ability to implement cognitive control continue to develop throughout adolescence and into early adulthood (Spear, 2000a). Furthermore, these capacities are extensively linked at both a conceptual and neurological level. While emotion plays an important role in regulating behavior, emotional reactions must also frequently be regulated cognitively in order to permit adaptive behavior, such as when anger or fear must be controlled or temptation avoided. These processes are mediated by subcortical brain regions such as the amygdala as well as by cortical regions. In particular, areas crucial for cognitive control are found in the prefrontal cortex (e.g. Robbins, Weinberger, Taylor, & Morris, 1996). Much like the

mental functions they subserve, these brain regions are extensively interconnected, forming a regulatory network that continues to develop throughout adolescence. The development of emotional processing and of cognitive regulatory abilities is likely to play a significant role in predicting both adaptive and maladaptive outcomes in adolescence (Dahl, 2001). Thus, our understanding of how emotions and cognitive regulation interact during adolescence may enhance our ability to help young people navigate the pitfalls of adolescence.

Cognitive development in adolescence may be characterized, in part, as the consolidation of regulatory systems under a set of executive functions. The cognitive skills typically grouped together under the title of executive functions include planning, conflict resolution, working memory and inhibitory control (Miller & Cohen, 2002). These capacities share a common aspect in that they play a supervisory role in cognition, regulating and coordinating seemingly more basic, or lower level, mental functions. In addition to their regulatory role in cognition, the executive functions are linked by their heavy reliance on the functioning of the prefrontal cortex (PFC) (Fassbender et al., 2004; Stuss & Levine, 2002; Sylvester et al., 2003). A number of MRI studies suggest that PFC has a highly protracted development relative to other parts of the brain, lasting well into the third decade of life (e.g. Giedd et al., 1996; Giedd et al., 1999; Gogtay et al., 2004; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999; Sowell, Trauner, Gamst, & Jernigan, 2002; Toga, Thompson, & Sowell, 2006). In particular, these studies find increased white matter/myelination and decreasing grey matter volumes, which may reflect dendritic pruning, in the PFC across adolescence (Giedd et al., 1999; Gogtay et al., 2004; Sowell et al., 1999; Sowell et al., 2002). These neurological developments are

often interpreted as the refining of processing via the production of more efficient circuits both within the PFC and between the PFC and other brain regions. In parallel to these findings, studies of cognitive functioning in adolescence have reported age-related improvements in both accuracy and reaction time on a variety of tasks requiring executive functions such as working memory (e.g. Hooper, Luciana, Conklin, & Yarger, 2004; Huizinga, Dolan, & van der Molen, 2006), task switching (e.g. Huizinga et al., 2006; Rubia et al., 2006) and inhibitory control (e.g. Casey et al., 1997b; Durston et al., 2002; Hooper et al., 2004; Johnstone, Pleffer, Barry, Clarke, & Smith, 2005). Furthermore, functional neuroimaging studies have suggested that the neural correlates of executive function also continue to change during the second decade of life. For example, studies using functional magnetic resonance imaging (fMRI) have found a shift from diffuse to more focal activity in prefrontal cortex between late childhood and early adulthood during performance of a task requiring inhibitory control (Casey et al., 1997b; Durston et al., 2006). Other fMRI studies have suggested that increased recruitment of dorsolateral PFC and some parietal regions underlies improved working memory performance with age (Crone, Wendelken, Donahue, van Leijenhorst, & Bunge, 2006; Scherf, Sweeney, & Luna, 2006). The relatively late consolidation of such neural circuits and cognitive skills may render adolescents particularly vulnerable to disruption by intense emotions, which could increase the likelihood of impulsive actions as well as failures to attend to and remember neutral or non-emotional stimuli in favor of distracting, emotionally salient information.

Self-regulation in adolescence is made more difficult by motivational and affective changes that appear to accompany the onset of puberty (Dahl, 2001; Romeo,

2003; Spear, 2000a). For example, a study of self-reported mood in children and teens found a 50% drop in the amount of time spent feeling 'very happy' with the transition to adolescence. These teens also described themselves as 'self-conscious' or 'embarrassed' two to three times more often than their parents reported feeling these emotions (Arnett, 1999). The gap between early adolescent changes in emotional reactivity and the development of efficient cognitive control may be one factor underlying the dangerous risk-taking behaviors displayed by many adolescents (Steinberg et al., 2006) as well as the increased incidence of many psychological disorders during this period. To date, few studies have directly examined the influence of emotion on executive function in adolescence.

Previous Research on Executive Function and Emotion in Adolescence

Emotion and inhibitory control in adolescence. Much of the research on executive function in adolescence has focused on aspects of inhibitory control, likely due to adolescents' apparent difficulty in regulating impulsive responses. Inhibitory control is a critical executive task, subserved largely by the anterior cingulate cortex and late-developing prefrontal brain regions, including inferior frontal, middle frontal and orbital frontal cortex (Bush, Luu, & Posner, 2000; Casey et al., 1997a; Durston et al., 2002). The term inhibitory control, in an experimental context, is most often used to refer to response inhibition, or the ability to refrain from making a prepotent response. Response inhibition is frequently tested using a go-nogo task. In a go-nogo paradigm, participants are asked to respond with a button press to every one of a series of sequentially presented stimuli except for a specific target, often an 'X' in a string of letters. The nogo stimulus,

on which the participant must refrain from pressing, is presented on only a small percentage of trials (usually 10-30%). Participants thus acquire a prepotent tendency to respond and must actively inhibit button pressing when the nogo stimulus appears.

Hare et al. (2008) studied the influence of facial expressions of emotion on brain activation during the performance of a go-nogo task using event-related fMRI. Participants between the ages of 7 and 32 years were split into three groups – children, adolescents and adults. Results showed greater amygdala activity when comparing fear and neutral trials in adolescents versus adults. This activity was also greater in adolescents when compared to the younger group, suggesting a non-linear pattern of development in amygdala reactivity in some circumstances. Measures of functional connectivity between frontal and amygdala activation showed that higher levels of connectivity correlated negatively with anxiety in the adolescent group, suggesting that cortico-limbic connections may be one factor contributing to individual differences in emotion regulation. Reaction time data for this study found adolescents and children had slower reaction times on fear trials compared to adults while only children had significantly slower reaction times on happy and calm face trials compared to the other two age groups. This pattern, coupled with the imaging results, suggests adolescents may be more susceptible to negative emotional interference compared to other age groups. However, no differences in accuracy on inhibitory trials due to either age or emotion were reported. This is likely due the use of event-related MRI, which requires variable and often extremely long inter-stimulus intervals, which may have prevented the acquisition of a strong prepotent tendency to respond.

Lewis, Lamm, Segalowitz, Stieben, & Zelazo, (2006) used event related potential (ERP) measures to examine go-nogo performance in neutral and negatively valenced circumstances across late childhood and adolescence (ages 7-16 years). Results of this study showed a steady rise in go-nogo performance accuracy and reduction in reaction time with increasing age. In addition to a traditional go-nogo task, participants were tested on a go-nogo task that involved the induction of a negative emotion: in one of the blocks, the participant was set up to lose all his or her points towards a valued prize. The average N2 amplitude for correct nogo trials, interpreted as a measure of effort, showed an increased difference between emotional versus non-emotional blocks in the older adolescent age groups (ages 13-14 and 15-16 years). These findings support the idea that behavioral inhibition in the presence of emotional arousal becomes less automatic and more effortful for a period during adolescence. However, this study did not report any behavioral differences in the influence of negative emotion induction on go-nogo performance (accuracy or reaction time) between age groups.

Monk et al. (2003) investigated the interaction of emotion and executive attention in adolescence. Participants in this study were asked to make decisions about facial expressions of emotion presented to them during fMRI scanning. In one condition, attention was explicitly focused on the emotion of the face, by having the participant identify each emotion. In a second condition, attention was focused on a non-emotional aspect of the faces (the width of the nose), making the emotion of the face an irrelevant distraction for task success. In a third condition, participants passively viewed the faces. Adults (25-36 years) were found to modulate orbitofrontal recruitment depending on attentional task demands while adolescents (9-17 years) showed no differences in

activation in this area between tasks. Looking at fearful faces only, when emotion was not task relevant (nose width judgment), adolescents showed more amygdala activation than adults, suggesting a failure to screen out irrelevant emotional information. During passive viewing, adolescents showed a greater differential in activation between fearful and neutral faces, compared to the adult group, showing increased activation for fearful faces in anterior cingulate cortex, orbitofrontal cortex and amygdala. Thus, while the adult group showed modulation depending on attention demands, adolescents showed more activation differences due to the emotional nature of the stimuli. This pattern fits well with the suggestion of immature cognitive regulation and strong emotional reactivity in adolescents versus adults.

Emotion and working memory in adolescence. The development of working memory in adolescence has been investigated in a number of both behavioral and imaging studies. Behavioral results are varied, with some studies reporting adult levels of working memory functioning by early adolescence (e.g. Asato, Sweeney, & Luna, 2006; Crone et al., 2006) while others show improved performance through the late adolescent years (e.g. Hooper et al., 2004; Luciana, Conklin, Hooper, & Yarger, 2005). This variability can be accounted for by the relative sensitivity and difficulty of the task used in any given study. A variety of behavioral tasks are used to tap working memory. Some of these tasks stress simple maintenance of information across a delay while others require the individual to actively manipulate information. Still other working memory tasks require continuous updating of items in working memory. One such task is the n-back. The n-back requires participants to identify whether or not each stimulus in a

sequence matches the stimulus presented a specified number ("n") of items prior.

Ladouceur et al. (2005), using a sample of 8- to 16-year-olds, investigated the influence of emotional background images (from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2001)) on performance on the n-back task. This study found that accuracy on this task increased with age. A comparison of a clinically depressed group of teens with healthy controls showed that depressed participants responded more slowly on trials with negative versus positive backgrounds while control participants responded more slowly on positive trials. Thus, results suggest that differences in the processing of task-irrelevant emotional information can influence adolescents' capacity for inhibitory control. The focus of the study by Ladouceur et al. (2005), however, was not normative developmental improvements in the ability to ignore emotional distraction during an executive task, but rather to examine the influence of psychopathology on such abilities during the adolescent period. Thus, the study did not include enough healthy adolescents in any age group to successfully examine developmental differences during adolescence. In fact, very few studies have examined the influence of emotional information on working memory tasks in healthy adolescents.

The studies discussed in this dissertation aim to characterize normative development across adolescence, looking primarily at the effect of age on how readily executive function (both inhibitory control and working memory) is disrupted by emotionally salient information.

Thesis Overview

The following chapters describe four studies that explore normative changes in the relationship between executive function and emotion during adolescence and early adulthood. The first chapter describes a study in which a sample of adolescents ranging from 11 to 25 years of age was asked to perform a go-nogo task in which task-relevant stimuli (letters) were presented at the center of large task-irrelevant emotional images. Similar to the working memory study by Ladouceur et al. (2005), participants in this go-nogo paradigm were asked to ignore the images and focus attention on the letters to the best of their ability. The background images were selected to be emotionally salient and were grouped into negative, positive, and neutral emotion categories. Scrambled versions of these images were also used as backgrounds in order to provide a condition with visually interesting backgrounds but no recognizable image. Participants were asked to press the space bar as quickly as possible for every one of a series of letters that appeared on the screen, with the exception of the letter 'X' for which they were told to not press. Results suggested that the ability to withhold a prepotent response is differentially affected by emotional distraction within certain age-ranges during adolescence.

The second chapter describes a study in which fMRI and a modified version of the task introduced in chapter one were used to explore the neural correlates of response inhibition in conditions with and without emotional distraction. Two age groups – 13-14 years old and 20-22 years old – were compared in terms of both their performance on the task and the brain activity elicited by emotion-laden versus more emotionally neutral conditions. Regions of differential activity between the two age groups included several

regions in prefrontal cortex that may be relevant for emotion regulation and cognitive control.

The third chapter extends the emotional-distraction paradigm introduced in the first and second chapters to a new aspect of executive function: working memory. In this study participants again ranged from 11 to 25 years of age. These participants completed both a shortened version of the original emotional-background go-nogo task and also an n-back working memory task with emotional images similarly presented in the background of the task-relevant letters. Results of this study suggest that the presence of emotional distraction interacts differently with different executive tasks across adolescence.

The fourth chapter explores environmental and genetic factors influencing susceptibility to emotional distraction in early adolescence. To this end, the study focuses on a sample of children raised in an institutional setting prior to international adoption. This population is of particular interest in part because of elevated rates of cognitive and emotional issues. This group also presents an opportunity to study the effects of early stress in the context of current high-quality care. This study uses the go-nogo paradigm introduced in the preceding chapters to explore the influence of emotional distraction during an inhibitory control task in this group of young adolescents who experienced significant stress in early childhood but who have subsequently been adopted into more nurturing environments. Participants in this study were 12-14 years of age and were all internationally adopted following a period of orphanage care. These participants were also genotyped for the val66met polymorphism on the BDNF gene. The Met polymorphism of this gene has been associated with poorer outcomes following stress

(Gatt et al., 2009; Perroud et al., 2008) Results suggest an interaction between the duration of early stress and BDNF genotype. As predicted, the combination of a late adoption age and possession of at least one Met allele was associated with higher rates of impulsive errors and greater susceptibility to emotional distraction.

Together these studies contribute to our understanding of how adolescent cognition is affected by irrelevant emotional background information. Such information may ultimately inform our general understanding of the factors contributing to adolescent decision-making and behavior and how best to help individuals successfully navigate the teen years.

Chapter 1: Response Inhibition During Emotional Distraction Across Adolescence

The first study aimed to begin exploring the changing interface between cognition and emotion and to identify any age ranges in which emotion has a heightened influence over executive function. In particular, this study examined changes across adolescence in the ability to inhibit a prepotent response while ignoring background images containing different types of emotional content. Participants ranging from 11 to 25 years of age were tested on a go-nogo task in which task-irrelevant emotional background images needed to be ignored. Go-nogo performance has been found to improve gradually across this age range under non-emotional conditions (Eigsti et al., 2006; Hooper et al., 2004; Huizinga et al., 2006). However, some studies have suggested heightened sensitivity to emotional context during performance of a higher-level cognitive task during early adolescence relative to other ages – both older and younger (Hare et al., 2008; Lewis et al., 2006; McGivern, Andersen, Byrd, Mutter, & Reilly, 2002). By testing participants across this age range we aimed to learn whether go-nogo performance would show a dip in the ability to screen out emotional distraction around the time of puberty or whether the disruptive quality of the images would change in a more linear manner across adolescence.

We hypothesized that go-nogo performance, as measured by accuracy on inhibitory trials, would improve with age. We also expected the presence of emotional (positive or negative) rather than neutral or scrambled images in the background to disrupt performance (i.e. slow reaction times and lower accuracy) across age groups. However, we expect this disruption to be largest in the younger adolescent groups. These

results would support the idea that interaction between prefrontal cortex and emotion-processing brain areas changes during the adolescent years and that, as a consequence, cognitive control systems could be more readily disrupted by emotional input in early adolescence relative to other ages.

Methods

Participants

One hundred participants (20 participants (10 male) in each of 5 age groups: 11-12 years (mean age = 11.49), 13-14 years (mean age 13.98), 15-16 years (mean age = 16.15), 18-19 years (mean age = 19.15) and 20-25 years (mean age = 21.91) were included in this sample. Adult participants were recruited from the undergraduate population of the University of Minnesota and received either payment or points towards class credit as compensation for their time and effort. Adolescents were recruited from a list, maintained by the Institute of Child Development at the University of Minnesota, of local families who are interested in research opportunities for their children. Adolescents were paid for their participation and parents were also compensated for travel expenses. All participants were verbally screened for neurological and psychological disorders as well as serious medical issues and learning disabilities. While at the lab, participants also completed a series of standardized questionnaires that probed anxiety levels (STAI for adults and STAI-C for adolescents), attention skills (CAARS for adults and Conner's Parent Rating Scale for adolescents) and general functioning (SCL-90 for adults and the Achenbach CBCL and YSR for adolescents). Participants who scored within the clinical range on these questionnaires were removed from subsequent data analyses and replaced

with new participants to produce the final sample of 100. An additional three males were tested in the 11-12 year-old group, two males and one female in the 13-14 year-old group, one male and two females in the 15-16 year-old group, two males and two females in the 18-19 year-old group, and 1 male and 2 females in the 20-25 year-old group. All recruitment and experimental procedures were approved by the Institutional Review Board of the University of Minnesota.

Behavioral Task

This study used a behavioral paradigm that combined an inhibitory control task, the go-nogo, with positive, negative and neutral images selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2001). In this task, letters were presented sequentially in a small box at the center of the computer screen. Participants were asked to respond as quickly as possible with a button press to every one of the letters, except for a specific target: an 'X.' The letters used included P, H, R, S, T and X. The Xs appeared on 25% of total trials such that participants acquired a prepotent tendency to press and needed to actively inhibit their response during nogo trials. The task required high levels of sustained vigilance as well as conscious control of a potentiated behavior.

The IAPS slides are a collection of standardized images selected to span a wide range of content. Each of these images has been given a normative rating on a scale from one to nine for two emotional dimensions: arousal, ranging from not arousing (1) to highly arousing (9), and valence, ranging from unpleasant/negative (1) to pleasant/positive (9). Normative ratings of the IAPS slides are not available for

adolescents, though work with a subset of these images has suggested that subjective ratings are not significantly different between adult and adolescent age groups (McManis, Bradley, Berg, Cuthbert, & Lang, 2001). These images were used as backgrounds for the go-nogo letter stimuli. Images were selected to be appropriate for young adolescents. Thus, the most arousing slides (erotica, mutilation images, and some violent scenes) were removed from the set. From the remaining slides, we selected 120 slides with highly positive valence ratings (average valence rating = 7.32, average arousal rating = 4.94), 120 slides with highly negative valence ratings (average valence rating = 3.12, average arousal rating = 5.32), and 120 slides that were as close to the neutral rating as possible (average valence rating = 5.25, average arousal rating = 3.35). Due to the naturally arousing nature of emotional stimuli and restrictions on what content was considered appropriate for our age group of interest, it was impossible to equate the three image groups in terms of arousal ratings. In order to create an emotionally neutral control condition that did not include any potentially distracting object information, we scrambled each of the selected IAPS images using a 32X32 grid. The resulting images were visually complex but had no discernable object content.

The task was presented using E-Prime software on a 21" monitor. Participants were seated comfortably at a viewing distance of approximately 32". Background stimuli covered the entire screen. Trials began with presentation of a white fixation cross on a grey background for 500 ms. The fixation screen was followed by an IAPS image presented alone for 350 ms before a small white box (0.4" x 0.4") containing the black target letter appeared in the center of the screen. Both letter and image remained on the screen for an additional 650 ms, completing the trial (See Figure 1). Participants were

instructed to respond as quickly as possible by pressing the space bar if the letter presented was any letter other than X (go trial). If the letter was an X, they were required to withhold their response (nogo trial). Responses (press or no press) and reaction times were recorded by the computer. Responses were considered valid if they occurred within the stimulus presentation or less than 100 ms into the subsequent fixation screen presentation. This cutoff reduced potential skewing of the reaction time data and eliminated random button presses that were not truly associated with stimulus presentation.

Participants completed the task in three runs. The structure of the task is depicted in Figure 2. *Run one* consisted of 120 trials in which the background for the letter stimuli was always a scrambled image. The letter stimuli were presented in random order. In *run two*, the unscrambled images were used. Because emotional responding to any single image is likely to be highly variable between individuals (for example, some people like snakes while others fear them), the slides were grouped into blocks of twenty slides in which every image fell into one of the three valence groups: positive, negative or neutral. This ensured that across the entire block, all participants were reasonably likely to respond in the expected valence direction. Within the designated valence of a given block, the order of slide presentation was randomized. The order of the valence blocks was then counterbalanced across participants. There were a total of 360 trials in run two, split into eighteen blocks (six for each valence group). Each trial presented a different IAPS image. The order of letter presentation was randomized with the constraint that an equal number of Xs (five) fell within each block of twenty trials. Participants were given breaks to rest their eyes after each set of 120 trials. Within each set of 120 trials, an equal

number of positive, negative and neutral blocks occurred (two each) such that slides of a single valence would not be clumped together towards the beginning or the end of the task. Following completion of all 360 trials of the second run, participants completed *run three*, which was equivalent to the first run, consisting of 120 trials with scrambled backgrounds. Scrambled background trials were also grouped into sets of 20 based on the valence of the background image (prior to scrambling) and two sets of 20 trials of each valence were included in both scrambled-trial runs (1 and 3) in a random order. Runs one and three were used to look at possible practice and fatigue effects.

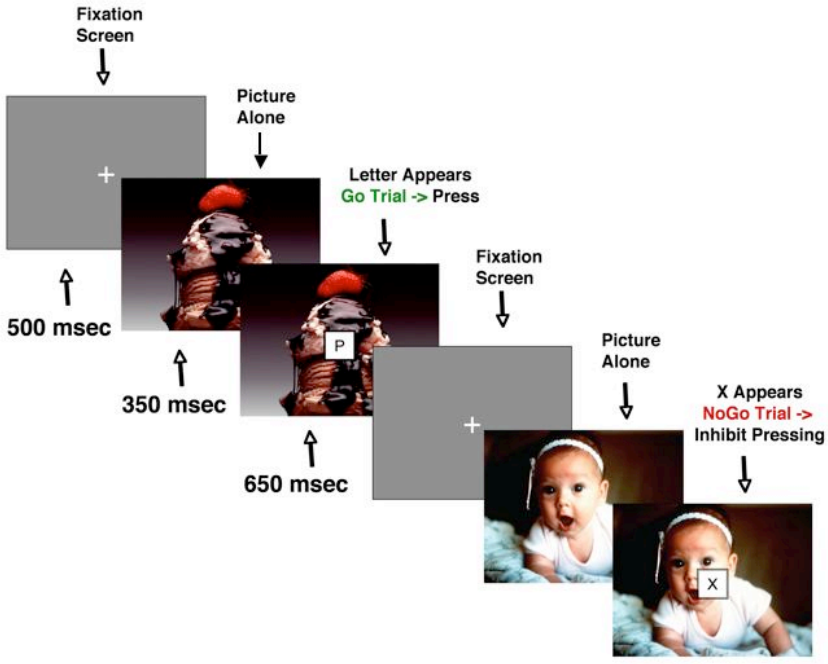

Figure 1. Sample trials of the emotional go-nogo. Task relevant letters were presented in a small box at the center of a background image selected from the International Affective Picture System (IAPS). Images were positive, negative, or neutral (positive examples are pictured here). Scrambled versions of these images were used as background in control blocks.

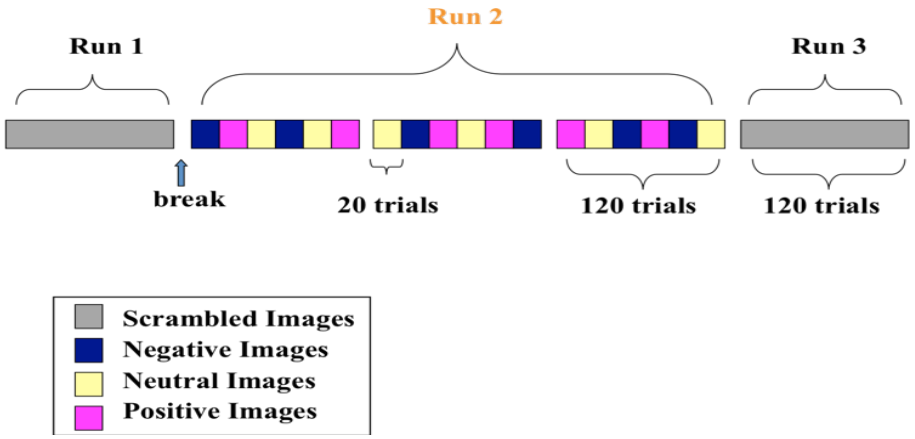

Figure 2. Run structure of the emotional go-nogo. Trials were split into three runs. Runs 1 and 3 consisted of trials with scrambled backgrounds. Run two consisted of trials with positive, negative or neutral backgrounds, grouped into blocks of 20 trials of each valence. Every set of 120 trials consisted of two of each valence blocks, presented in a randomized order.

Data Analysis

Reaction time data as well as response accuracy data were recorded for each participant in all three runs. Nogo trial accuracy, go trial accuracy and go trial reaction time were each analyzed via mixed-model ANOVAs including age group (11-12, 13-14, 15-16, 18-19, 20-25 years) and gender as between-subject factors and trial background type (negative, positive, neutral, scrambled) as a within subject factor. Greenhouse-Geisser corrections were used in cases where Mauchly's test indicted a violation of the assumption of sphericity. Significant effects of age group were followed up with Bonferroni-corrected *post hoc* comparisons. Significant effects of background were followed up using two-tailed paired-samples t-tests. Given the *a priori* hypothesis that adolescent groups would show diminished performance on negative and positive trials, relative to neutral and scrambled trials, while older groups would be less disrupted by emotional distractions, ANOVAs examining the effect of background content were

performed for each age group separately even in cases where a significant age group x background effect was not found. Results of these ANOVAs were followed up using paired samples t-test (two-tailed) comparing performance on the four background types.

Results

NoGo Trial Accuracy

Mean nogo trial accuracy for each group and background type is depicted in Figure 3. A 5 (age group) x 2 (gender) x 4 (background) mixed model ANOVA revealed main effects of age group ($F(4, 90) = 22.03$, $p < .001$, $\eta^2 = .495$) and background ($F(2.8, 248) = 18.90$, $p < .001$, $\eta^2 = .174$). *Post hoc* comparisons of performance between groups revealed significantly lower nogo trial accuracy between the youngest age group compared to all three older groups ($p < .001$). The 13-14 year-old group also performed worse on this metric relative to the 18-19 and 20-25 year-old groups ($p < .05$ and $p < .001$, respectively).

Looking at all age groups together, overall effects of background on nogo trial accuracy were found using paired sample t-tests, between negative background trials and scrambled ($t(99) = 5.92$, $p < .001$), neutral ($t(99) = 4.82$, $p < .001$) and positive ($t(99) = 4.19$, $p < .001$) background trials. In each case, accuracy was lower for negative background trials than for other types of trials. A more modest, but still significant, effect was also found between positive and scrambled background trials ($t(99) = 2.52$, $p < .05$) with accuracy being lower on positive relative to scrambled trials. However the presence of positively valenced background images did not have a significant effect on nogo trial accuracy relative to neutral images.

Three interaction effects were also revealed by the mixed model ANOVA. A significant interaction between background and age group ($F(2.8, 248) = 2.65$, $p < .01$, $\eta^2 = .106$) was found, as well as an interaction, at a trend level, between background and gender ($F(2.8, 248) = 2.64$, $p = .055$, $\eta^2 = .029$). A three way interaction between background, age group and gender ($F(2.8, 248) = 1.84$, $p < .05$, $\eta^2 = .076$) was also revealed.

In order to further explore these interaction effects, a 2 (gender) x 4 (background), mixed model ANOVA was performed for each age group. These separate ANOVAs showed no main effects of gender, but found a main effect of background in the three younger age groups: 11-12 years ($F(3, 54) = 7.00$, $p < .001$, $\eta^2 = .280$), 13-14 years ($F(3, 54) = 15.84$, $p < .001$, $\eta^2 = .468$) and 15-16 years ($F(3, 54) = 4.03$, $p < .05$, $\eta^2 = .183$). No significant effect of background was found in the oldest two (18-19 and 20-25 year-old) groups. An interaction effect between background and gender, was also found in only the 15-16 year-old group ($F(3, 54) = 7.57$, $p < .001$, $\eta^2 = .296$).

The main effects of background in the three youngest groups were followed up using paired-samples t-tests. The youngest group (11-12 years) showed significantly lower performance on negative relative to scrambled ($t(19) = 4.48$, $p < .001$) and neutral ($t(19) = 2.28$, $p < .05$) trials. This group also showed lower nogo accuracy on positive relative to scrambled ($t(19) = 3.74$, $p < .01$) trials. There were no other significant effects of background on nogo accuracy in this group. In contrast the 13-14 year-old group revealed significant differences between negative background trials and scrambled ($t(19) = 6.19$, $p < .001$), neutral ($t(19) = 3.91$, $p < .01$) and positive ($t(19) = 3.69$, $p < .005$) trials, with lower accuracy on negative trials in each case. This group also demonstrated

significantly lower nogo accuracy on both positive ($t(19) = 2.83$, $p < .05$) and neutral ($t(19) = 2.29$, $p < .05$) trials relative to scrambled background trials. The 15-16 year-old group showed significant differences between negative and neutral trials ($t(19) = 2.16$, $p < .05$) and between negative and positive ($t(19) = 2.46$, $p < .05$) trials. Accuracy on negative trials was again lower than on the other trials types. No significant differences in nogo accuracy, based on trial background type, were found in the two eldest groups.

In order to explore the background x gender interaction found in the 15-16 year-old group, performance on each background type was compared via paired-samples t-tests for each gender group within this age bracket. These analyses revealed that the female group performed significantly worse on negative trials relative to scrambled ($t(9) = 3.77$, $p < .01$), neutral ($t(9) = 3.49$, $p < .01$) and positive trials ($t(9) = 2.90$, $p < .05$). Males, however, showed significantly higher accuracy on negative compared to scrambled trials ($t(9) = 2.30$, $p < .05$) but not compared to neutral or positive trials. Males also showed significantly higher accuracy on positive versus scrambled trials ($t(9) = 2.36$, $p < .05$). Nogo trial accuracy for each gender, subdivided by age group and background is presented in Figure 4.

Practice and fatigue effects were examined via a 5 (age group) x 2 (gender) x 2 (run: 1 vs. 3) mixed model ANOVA. Results revealed a main effect of run ($F(1, 90) = 4.20$, $p < .05$, $\eta^2 = .045$) and also a main effect of age group $F(4, 90) = 15.56$, $p < .001$, $\eta^2 = .409$. The main effect of run was found to be due to a decrease in nogo trial accuracy between run one (mean accuracy = 79.8 sd = 13.0) and run three (mean accuracy = 77.6, sd = 16.2). The main effect of group was followed up using *post hoc* contrasts which revealed significantly lower accuracy in the 11-12 year-old group

compared to the 13-14 ($p < .01$), 15-16 ($p < .001$), 18-19 ($p < .001$), and 20-25 ($p < .001$) year-old groups. The 20-25 year-old group also showed significantly higher accuracy scores compared to the 13-14 ($p < .01$) and 15-16 ($p < .05$) year-old groups.

The ANOVA also revealed an age group x run interaction ($F(4, 90) = 2.74$, $p < .05$, $\eta^2 = .108$). Following up on this, paired sample t-tests comparing run 1 to run 3 for each age group revealed only one group in which there was a significant difference in nogo accuracy between the first and last run: the 11-12 year-old group. This group performed significantly worse, in terms of nogo accuracy, in the last run of the task compared to the first run.

Go Trial Accuracy

While accuracy on nogo trials best reflects the ability to withhold prepotent responses (ie. inhibitory control), accuracy on go trials was analyzed separately as a metric of sustained attention, a cognitive skill that may also improve during adolescence. The influence of age, gender and distracting emotional information on go trial accuracy was examined via a 5 (age group) x 2 (gender) x 4 (background) mixed model ANOVA. Results indicated main effects of both background ($F(2.3, 206) = 12.51$, $p < .001$, $\eta^2 = .122$) and age group ($F(4, 90) = 3.58$, $p < .01$, $\eta^2 = .137$) as well as a background x age group interaction ($F(9.1, 206) = 3.50$, $p < .001$, $\eta^2 = .134$). *Post hoc* comparisons of go accuracy between groups revealed significantly lower accuracy on go trials for the 11-12 year-old age group vis-à-vis the 15-16 year-old group ($p < .05$) and the 20-25 year-old group ($p < .05$). It is worth noting that these differences, while significant, reflect relatively small differences in mean accuracy – ranging only between 95 – 99% accuracy.

Thus, significant results may be in part due to very small amounts of variance produced by near-ceiling performance. Mean go accuracy for all age groups and backgrounds is presented in Figure 5.

Overall comparisons of go trial accuracy on trials with different types of backgrounds revealed effects paralleling those seen on nogo trial accuracy and go trial reaction time. Go trial accuracy was found to be significantly lower on negative background trials relative to scrambled ($t(99) = 3.92$, $p < .001$), neutral ($t(99) = 4.25$, $p < .001$), and positive ($t(99) = 4.08$, $p < .001$) trials. In order to follow up on the background x group effect, ANOVAs were performed to determine the effect of background in each group. Significant effects of background were found in four of the age groups: 11-12 years ($F(1.9, 42) = 6.56$, $p < .01$), 13-14 ($F(3, 54) = 2.75$, $p = .05$), 15-16 years ($F(1.6, 28) = 3.24$, $p < .05$) and 20-25 ($F(1.9, 34) = 5.94$, $p < .01$). No significant effect of background was found in the 18-19 year-old group.

In each of the groups showing background effects, paired-samples t-tests were used to compare go trial accuracy on each background type. In the 11-12 year-old group, accuracy was found to be significantly lower on negative background trials compared to scrambled ($t(19) = 2.70$, $p < .05$), neutral ($t(19) = 3.61$, $p < .01$), and positive ($t(19) = 2.12$, $p < .05$) trials. In the 13-14 year-old group, negative trials showed lower accuracy when compared to scrambled ($t(19) = 2.49$, $p < .05$) and positive ($t(19) = 2.16$, $p < .05$) trials, but not neutral trials. The 15-16 year-old group demonstrated significantly lower accuracy on negative versus scrambled ($t(19) = 2.17$, $p < .05$) and neutral ($t(19) = 2.38$, $p < .05$), but not positive trials. The 20-25 year-old group performed significantly worse, in terms of go trial accuracy, on negative compared to neutral ($t(19) = 2.66$, $p < .05$) and

positive ($t(19) = 3.10$, $p < .01$), but not scrambled trials. Unlike the other groups, the oldest group showed decreased accuracy on scrambled trials, when compared to both positive ($t(19) = 2.76$, $p < .05$) and neutral ($t(19) = 2.88$, $p = .01$) trials.

Performance on scrambled trials was further examined in a 5 (age group) x 2 (gender) x 2 (run: 1 vs 3) mixed-model ANOVA. This analysis revealed no main effect of run and no run x group interaction. A main effect of group ($F(4, 90) = 3.20$, $p < .05$, $\eta^2 = .124$) was found, paralleling that found for overall go trial accuracy. In this case, however, looking at scrambled trials alone, significantly lower accuracy was found in the 11-12 year-old group relative to the 13-14 year-old group ($p < .05$) and the 15-16 year-old group ($p < .05$).

Go Trial Reaction Time

Reaction time was computed for responses on correct go trials. Mean reaction times for all groups and background types are presented in Figure 6. In order to examine the effects of age, gender and emotion on reaction time, a 5 (age group) x 2 (gender) x 4 (background) mixed model ANOVA was run. Main effects were found for background ($F(2.4, 220) = 58.93$, $p < .001$, $\eta^2 = .396$) and age group ($F(4, 90) = 2.51$, $p < .05$, $\eta^2 = .100$). Results of this analysis also showed a trend level effect of gender ($F(1, 90) = 3.75$, $p = .056$, $\eta^2 = .040$) in which females showed longer reaction times than males. There were no significant interaction effects between any of the variables included in this ANOVA.

The main effect of age group was followed up using *post hoc* contrasts. However, no significant differences between individual groups were found. The main effect of

background was explored further via paired-samples t-tests, comparing reaction times for each background type. These tests revealed that reaction times were significantly longer for negative background trials compared to scrambled ($t(99) = 10.47$, $p < .001$), neutral ($t(99) = 8.08$, $p < .001$), and positive ($t(99) = 9.63$, $p < .001$) backgrounds. Reaction times were also found to be significantly faster on scrambled trials, when compared to neutral ($t(99) = 4.53$, $p < .001$) and positive trials ($t(99) = 4.76$, $p < .001$).

In keeping with the *a priori* hypothesis that adolescent groups would show diminished performance on trials involving emotional distraction, while older groups would be less readily disrupted, ANOVAs examining the effect of background content on reaction time were performed for each age group separately. Significant main effects of background content on reaction time were found for each age group: 11-12 years ($F(2.1, 37.5) = 7.42$, $p < .01$, $\eta^2 = .292$), 13-14 years ($F(2.1, 37.1) = 19.69$, $p < .001$, $\eta^2 = .522$), 15-16 years ($F(3, 54) = 21.84$, $p < .001$, $\eta^2 = .548$), 18-19 years ($F(3, 54) = 8.50$, $p < .001$, $\eta^2 = .321$), and 20-25 years ($F(3, 54) = 15.3$, $p < .001$, $\eta^2 = .460$). Paired samples t-tests were then used to compare reaction times for each background type within each age group. The 11-12 year-old group showed significantly longer reaction times for negative trials as compared to scrambled ($t(19) = 3.63$, $p < .01$), neutral ($t(19) = 2.62$, $p < .05$), and positive ($t(19) = 3.13$, $p < .01$) trials. This group also showed an effect of increased reaction times on trials with positive backgrounds. This effect, however, was only significant in comparison to scrambled background trials ($t(19) = 2.59$, $p < .05$).

The 13-14 year-old age group also showed significant differences in mean go trial reaction time as a function of background content. Like the 11-12 year-old group, reaction times on negative trials were significantly slower than on the three other

background categories (scrambled: $t(19) = 5.87$, $p < .001$; neutral: $t(19) = 4.59$, $p < .001$; positive: $t(19) = 6.08$, $p < .001$). Reaction times on scrambled background trials were also significantly faster than both positive ($t(19) = 3.51$, $p < .01$) and neutral ($t(19) = 3.60$, $p < .01$) trials. Results for the 15-16 year-old group revealed a similar pattern, with longer reaction times on negative background trials, compared to scrambled ($t(19) = 6.75$, $p < .001$), neutral ($t(19) = 5.02$, $p < .001$), and positive ($t(19) = 6.08$, $p < .001$) trials. This age group also showed significantly longer reaction times for neutral than for scrambled trials ($t(19) = 2.81$, $p < .05$) as well as a trend for slower responses to positive versus scrambled background trials ($t(19) = 2.01$, $p = .058$). The two oldest groups, however, showed no significant differences between scrambled and positive or neutral trials. In the 18-19 year-old group, negative trial reaction time was significantly longer than for scrambled ($t(19) = 4.56$, $p < .001$), neutral ($t(19) = 3.06$, $p < .01$), and positive ($t(19) = 3.16$, $p < .01$) trials. Similarly, in the 20-25 year-old group, responses were significantly slower on trials with negative backgrounds, as compared to scrambled ($t(19) = 4.56$, $p < .001$), neutral ($t(19) = 5.44$, $p < .001$), and positive ($t(19) = 5.31$, $p < .001$) backgrounds. Thus, in summary, all five age groups demonstrated significantly slower responses on negative trials, as compared with all other trial types. The three youngest groups also showed some evidence of faster responses on scrambled background trials versus positive and neutral image trials, though these effects were less consistently significant.

The first and last runs, consisting of all scrambled-background trials, were used as a check for potential age and gender differences in fatigue and practice effects on reaction time. A 5 (age group) x 2 (gender) x 2 (run: 1 vs 3) ANOVA revealed main effects of

age group ($F(4, 90) = 2.49$, $p < .05$, $\eta^2 = .100$), gender ($F(1, 90) = 3.71$, $p = .57$, $\eta^2 = .040$), and run ($F(1, 90) = 48.23$, $p < .001$, $\eta^2 = .349$). However, no interaction effects were found. The effect of age group was followed up with *post hoc* contrasts between nogo reaction times in each group. Results showed no significant differences between age groups and only one trend-level difference ($p = .066$) between the 11-12 and 15-16 year-old groups. The main effect of gender reflected females having significantly longer reaction times (mean = 377.4, sd = 48.9) than males (mean = 361.5, sd = 33.5). The main effect of run reflected an overall reduction in response time between the first (mean = 378.6, sd = 46.9) and last (mean = 360.2, sd = 42.1) runs.

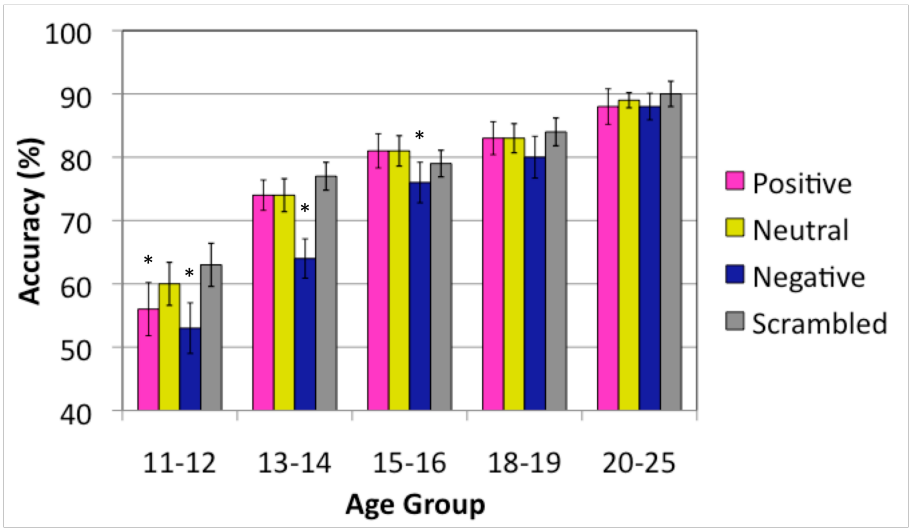

Figure 3. Accuracy on nogo trials for all age groups and background types.

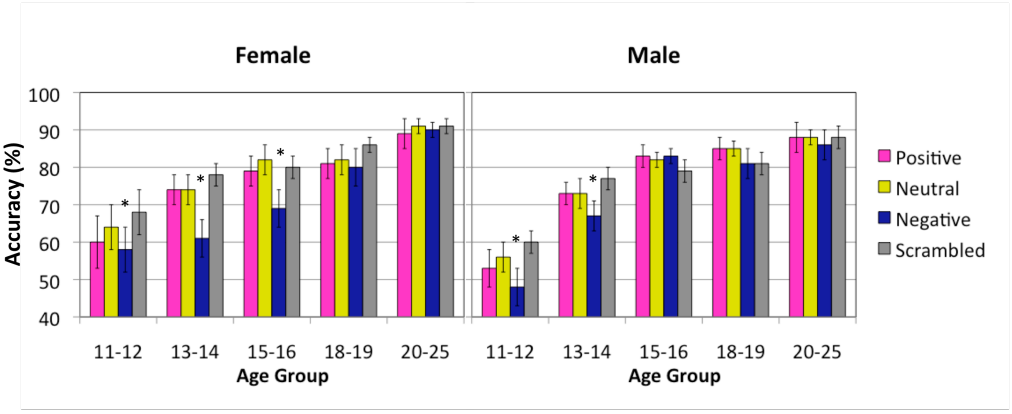

Figure 4. Accuracy on nogo trials for males versus females in all age groups and background types.

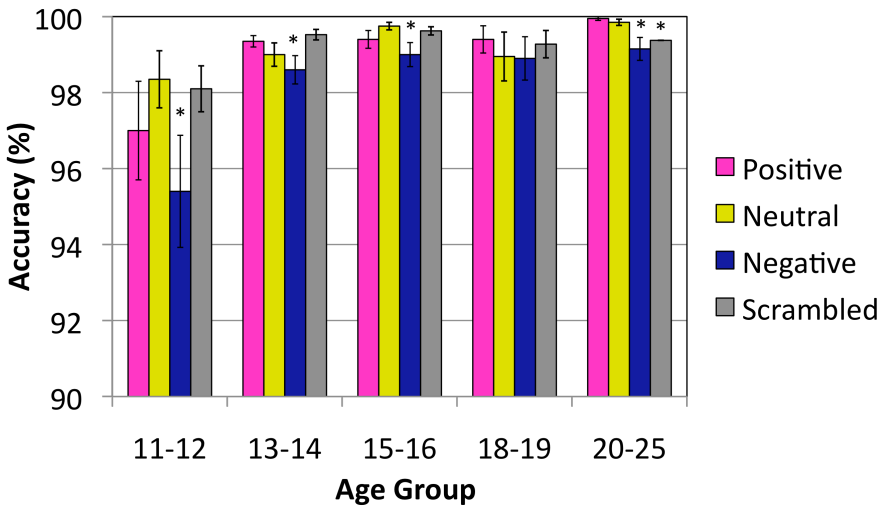

Figure 5. Accuracy on go trials for all age groups and background types.

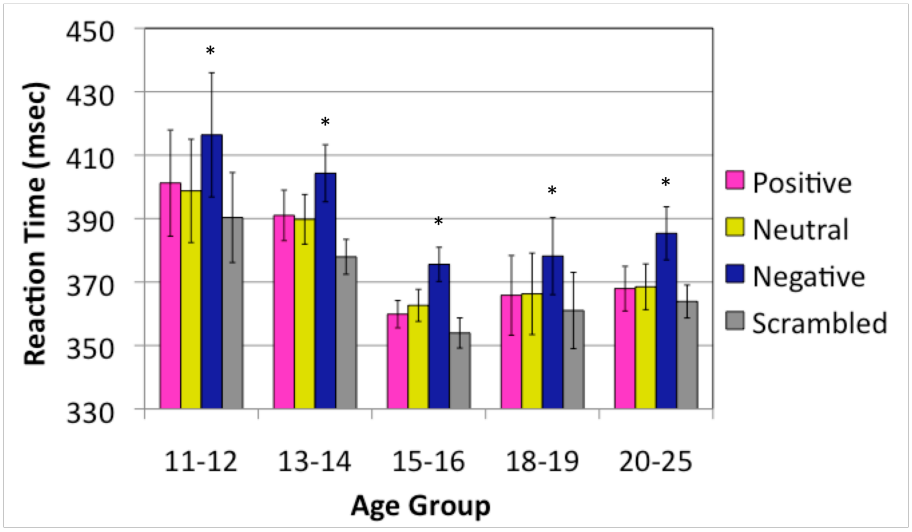

Figure 6. Reaction times on correct go trials for all age groups and background types.

Discussion

Results of this study support the hypothesis, based on multiple previous studies (e.g. Casey et al., 1997b; Durston et al., 2002; Hooper et al., 2004; Johnstone et al., 2005), that go-nogo performance would improve with age throughout adolescence. Results also bear out the prediction that younger adolescents, when required to exert inhibitory control over a potentiated response, are more readily disrupted by irrelevant emotional information than are older adolescents and adults. That is, the three youngest age groups showed significant effects of background on nogo accuracy that were not seen in the two eldest groups. This pattern is consistent with a model of adolescent cognition in which not only does inhibitory control show a highly protracted development, but also in which emotional inputs may more easily derail regulatory efforts during this period.

Comparisons of accuracy on inhibitory trials on the four different background types revealed the negative images to be the most disruptive to successful response inhibition in all three of the younger age groups. In the youngest group (11-12 years), however, there was also evidence that positive images detracted from task success when compared to scrambled trials. Even in this age group, however, there was no evidence that positive images were significantly more disruptive than neutral ones. The more limited influence of positive images on task performance may be due to slightly lower arousal in the positive images images (4.94 on the Self-Assessment Manikin (SAM)) scale versus 5.32 on the negative images) or could reflect an instinctual orienting response to potentially dangerous stimuli that is very difficult to override.

While the two youngest age groups showed no interaction between gender and background on nogo accuracy, the 15-16 years old group revealed different patterns of responding between the two genders. While males in this age range actually showed significantly higher nogo accuracy rates on both positive and negative compared to scrambled trials, females showed a response pattern similar to that seen in the 13-14 year-old group. That is, females showed a distinct disadvantage on negative trials compared to all other trial types. This finding suggests that adolescent females may remain susceptible to negative emotional distraction for a longer period than adolescent males. This result closely parallels findings in the clinical literature that show depression and anxiety rates that are particularly high in females within this age range. One must be cautious, however, in interpreting these results due to the absence of *a priori* hypotheses regarding gender and the small size of each subgroup, defined by both age and gender. Furthermore, it is not clear from the current study whether the increased disruptiveness of negative images in the younger age groups and in 15-16 year-old females was due to reduced capacity for top-down control of attention and action or by increased salience of the emotional information for these groups. It is likely both factors influence performance to some degree.

Accuracy on go trials, though not a direct measure of inhibitory control, showed age and background effects not unlike those found on inhibitory trials, with improved performance with age and lower accuracy on negative-background trials relative to other trial types. This finding raises the question as to whether the effect of emotional distraction is truly specific to executive function or whether the emotional images disrupt a more general attentional process. However, there was no interaction between age and

the disruptive impact of the negatively valenced images for go trial accuracy. That is, go trial accuracy was generally lower for negative trials across the full age range tested. It is possible that the lack of an interaction between age group and slide background occurs because performance on go trials relies less on functioning of prefrontal cortex and therefore the relevant neural substrates for go trial accuracy are not developing as rapidly across adolescence as those necessary for successful inhibition on nogo trials. It is, however, difficult to interpret results for a measure where performance is very close to ceiling and variability is extremely low.

Differences in average reaction time on go trials also revealed relatively little in the way of developmental change. Despite an overall main effect of group, individual comparisons of reaction times between groups revealed no significant differences. Females showed significantly slower overall responding than males, but this effect did not interact with age group. Furthermore, significant effects of background valence on go trial reaction time were present in all age groups, with negative slides showing the slowest reaction times in each group. This pattern of results suggests, much like the go trial accuracy data, that the emotionally negative information is, in fact, at least somewhat salient in all five age groups. The slowed responding on the negative trials suggests that these images did capture attention in all five age groups. The key difference however, is that the older groups were still able to maintain high rates of accuracy on the inhibitory trials, even while distracted by the negative emotional information.

Practice effects were seen across age groups in the form of diminished reaction times between the first and last runs of the task (scrambled trials only). However, only one age group – 11-12 years – displayed a potential fatigue effect, with reduced accuracy

on nogo trials between runs one and three. This effect could be interpreted as fatigue, boredom with the task, or a lingering effect of the emotional content of the preceding run.

In this study, behavioral changes in response inhibition and the susceptibility to emotional distraction were observed at a point in development when brain areas critical for self-regulation are being restructured and refined, raising questions about the relationship between neurological development and adolescents' ability to control their behavior under emotional circumstances. These questions are further explored in chapter two, through the use of a similar task and functional MRI.

Chapter 2: Neural Correlates of Response Inhibition During Emotional Distraction

The executive functions and their underlying neural correlates do not fully mature until early adulthood. This protracted developmental course may leave executive task performance particularly vulnerable to disruption while regulatory skills are not fully mature. Concurrent changes are seen around the time of puberty in the dopaminergic inputs to the mesolimbic/striatal systems mediating affect and reward oriented behavior (Spear, 2000a). The combination of a still-maturing prefrontal cortex and changing inputs from emotion-processing areas of the limbic system may combine to produce poor performance for adolescents relative to adults on tasks that emphasize executive function, and also a larger decrement in performance in the presence of emotional distractors. In chapter one, such behavioral effects were found using a go-nogo task in which emotional images were presented in the background of task-relevant stumuli. However, these behavioral results had not yet been tied, in a direct way, to changes in brain activity in prefrontal or limbic regions. The current study uses fMRI in conjunction with a modified version of the go-nogo task introduced in chapter one to examine whether differences in activation are observed in relevant brain regions between young adolescents (13-14 years) and young adults (20-22 years) during performance of this task.

Previous studies, such as that by Casey et al. (1997b) comparing activation in children and adults during a non-emotional go-nogo task have reported no age-dependent differences in the location of activation in prefrontal cortex. However, Casey et al. (1997b) did report differences in the extent of activation in dorsal and lateral prefrontal

cortex, with the younger age group showing more extensive or diffuse activation. However, this initial study did not include adolescent participants. Tamm, Menon, and Reiss, (2002) used a similar go-nogo task but extended the age range studied through adolescence instead of including only children and adults. This study found positive correlations between activation and age in left inferior frontal gyrus and oribitofrontal gyrus as well as negative correlations between age and activation in left middle and superior frontal gyri. This study reported no differences in behavioral measures of inhibitory control (i.e. nogo accuracy) between groups, athough they did report decreasing reaction times with increasing age on go trials. The lack of difference in accuracy scores may be due to the high probability of nogo trials (50%), creating a relatively weak tendency to press. This study did not include any emotional component in the go-nogo task.

As described previously in the general introduction, Hare et al. (2008) found increased amygdala activation in adolescents relative to both children and adults when required to respond to emotional faces during a go-nogo task. This study used event related fMRI, allowing the researchers to examine the brain responses to each emotional face stimulus. However, this design required a much slower stimulus presentation rate than is typical in response inhibition paradigms, potentially reducing the inhibitory demands for the participants. The behavioral task also required interpretation of the facial expression of emotion and therefore no conflict existed between attending to the emotional information and successfully completing the task. Because of differences in design, it is difficult to extrapolate from the findings of prior MRI studies to predict what

age differences in activation might emerge given a more standard go-nogo paradigm and the inclusion of emotional distractors.

In this study addresses three main hypotheses. The first hypothesis is that limbic regions including amygdala and orbitofrontal cortex will be differentially activated during inhibitory control in negative or positive versus neutral blocks, given the arousing nature of the emotional background images (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). The second hypothesis is that an age by emotion interaction will emerge for activity in prefrontal cortex when a negative > neutral contrast or a positive > neutral contrast is compared between age groups. Our third hypothesis is that prefrontal cortex activation will show developmental differences between the adult and adolescent groups during inhibitory control blocks compared to blocks that do not contain inhibition trials (scrambled > scrambled-all-go by group). In addition to these *a priori* hypotheses, we will explore the developmental differences in inhibitory control and brain activation that may occur in the response to basic image content (neutral > scrambled). We do not have specific predictions regarding prefrontal or limbic activation during this condition.

Methods

Participants

Participants included in this study were 12 adults (6 male) between the ages of 20-22 years (mean age = 21.4 years) and 17 adolescents (9 male) between the ages of 13-14 years (mean age = 13.6 years). Adult participants were recruited from the undergraduate population of the University of Minnesota. Adolescents were recruited from a database of local families maintained by the Institute of Child Development at the University of

Minnesota. Participants were paid for their participation and parents were compensated for travel expenses. All participants were screened for metal in or on their bodies, including braces, permanent retainers, and tattoos. Participants were excluded for personal histories of psychopathology or neurological damage or disorder. Participants were also excluded from participation if they were taking psychotropic medications or if they had previously participated in a study using the same behavioral task. In addition to the sample described above, three additional participants were tested but not included in analysis. One adult male was excluded from analysis due to excessive motion throughout the scanning session. Another adult male participant was excluded retroactively for not meeting study criteria. One adolescent female did not successfully complete the scan session and was also excluded from analyses. All participants were right handed. All recruitment and experimental procedures were approved by the Institutional Review Board of the University of Minnesota.

Behavioral Task

The task, based on our previous behavioral study, combined a go-nogo paradigm with emotionally arousing background images selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2001). In this task, letters were again presented sequentially in a small box at the center of the computer screen. As before, participants were asked to respond as quickly as possible with a button press to every one of a series of letters, except for the target letter: 'X.' Xs appeared on 25% of the total trials such that participants acquired a prepotent tendency to press and needed to actively inhibit their response during nogo trials. The same IAPS images used in experiment one

were again used as backgrounds for the go-nogo letter stimuli. Scrambled versions of these images were used to create a control condition.

The task was presented using E-prime software and synched to the scanner via TTL pulse. Timing of individual trials was the same as described in chapter one (See Figure 1). This rapid stimulus presentation preserved the integrity of the cognitive task – slowing down a go-nogo task greatly reduces the difficulty of inhibiting responses on nogo trials – but precluded the use of an event-related fMRI design. The relatively low frequency of nogo trials as well as the relatively large number of unique trial types also supported the use of a block design in order to keep the duration of the task manageable for our younger participants.

The task consisted of three runs of twelve blocks (6min, 12sec each run). Each block included 20 behavioral trials, 5 of which were nogo trials. Each run contained two blocks of each condition (positive, negative, neutral, scrambled), presented in a pseudorandom order. In addition, each run began and ended with a block of all go trials (20 trials, scrambled background) followed by a block of fixation rest (See Figure 7).

Responses (press or no press) and reaction times were recorded using an MRI compatible button box. Responses were considered valid only if they occurred during the 650 ms stimulus presentation or less than 100 ms into the subsequent inter-trial interval. This cutoff reduced potential skewing of the reaction time data and eliminated any random button presses that were not truly associated with stimulus presentation.

Nogo and go trial accuracy and correct go trial reaction time were analyzed using mixed model ANOVAs in which age group (13-14 vs. 20-22 years) and gender were

entered as between-subject factors and trial background (negative, positive, neutral, scrambled) was entered as a within-subject factor.

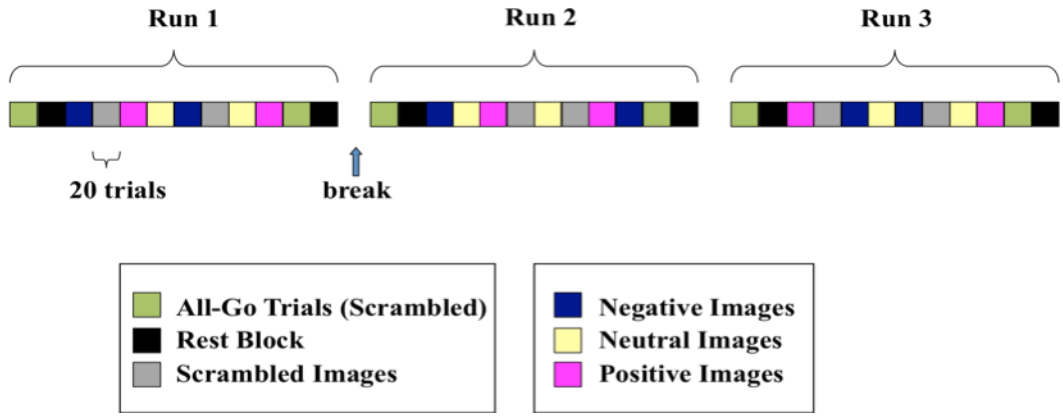

Figure 7. Run structure of emotional go-nogo for fMRI. Trials were split into three runs. Each run began and ended with a block of 20 go trials on scrambled image backgrounds, followed by a block of fixation rest (30 sec). The remaining blocks that made up the run were blocks of 20 trials of the same valence category (positive, negative, neutral). Two blocks of each valence were presented in each run in a pseudorandom order.

MRI Data Acquisition

The MRI scanning session began with a sagittal scout (10 sec) for purposes of prescribing subsequent images. Sagittal T1 MPRAGE images were then aquired (TR = 2530, TE = 3.65, Flip = 7^{o}, 240 slices, 1x1x1 mm voxel) for coregistration of functional images (10min, 49sec). Whole brain EPI BOLD images were acquired in three runs (6min, 12sec each run). Images were acquired in 34 interleaved, oblique slices on the Siemens 3T Trio Scanner (TR=2000, TE=28, Flip=90^{o}, FOV=200, matrix 64x64, 4mm slice thickness, repetitions=184). Slices were tilted 30^{o} coronally from the AC-PC plane

(T > C -30.0) to reduce susceptibility artifact in the ventral prefrontal cortex and amygdala.

MRI Image Analysis

Prior to analysis, preprocessing was performed on the raw functional images using Brainvoyager software, including slice scan time correction, linear trend removal, high-pass temporal filtering to remove nonlinear drifts, spatial data-smoothing with a 6mm Gaussian kernel, and three-dimensional motion correction. Runs showing mean motion greater than 0.5 voxels (1.5mm) were excluded. In the adolescent group, two runs - 1 each from two subjects - were excluded. In two other runs, also in the adolescent group, individual motion spikes beyond the 0.5 voxel threshold were removed from subsequent analyses. All participants contributed a minimum of two functional runs of data to the analyses. Functional data were co-registered to the anatomical volume and transformed into Talairach space.

Statistical analysis of the functional data was performed using a general linear model (GLM) with predictors for each block condition (positive, negative, neutral, scrambled) relative to baseline (fixation). Analyses were conducted in multiple steps. Contrasts were performed first for individual participants then combined into group level analyses to examine changes in activity across groups and conditions. All group-level analyses used random effects modeling with a dependent variable of percent change in signal. For analyses that included comparisons across age-groups, significance was determined using a contiguity threshold of 5 functional voxels and $p < .005$ to correct for multiple comparisons. For single age-group analyses, a more stringent contiguity threshold of 20 voxels and $p < .005$ was used.

Contrast analyses were performed based on t-test differences between the beta weights of predictors of interest to our primary hypotheses. Thus, in order to address the first two hypotheses, contrasts were performed comparing blood-oxygen-level dependent (BOLD) signal between negative and neutral conditions first in the adult group alone, followed by a contrast between age groups of negative > neutral activation. Subsequently positive > neutral activation was also compared between groups, as was activation between groups for neutral > scrambled blocks. In order to address hypothesis 3, group activation was compared for the contrast of scrambled go-nogo blocks > scrambled all-go blocks. While whole-brain analyses were performed, because all hypotheses addressed only a subset of brain areas – namely prefrontal cortex and the limbic system – only significant activity differences these areas will be discussed here. A full list of activation differences are presented in Appendix II.

Results

Behavioral Results

Nogo trial accuracy. Accuracy on 'nogo' trials was analyzed using a 2 (age group) x 2 (gender) x 4 (background) mixed model ANOVA. This analysis revealed a main effect of group ($F(1, 25)=11.28$, $p < .01$), with adults significantly outperforming teens (see Figure 8). No main effect of gender or background was found, as well as no significant interaction effects.

Go trial accuracy. A 2 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA was run to explore the effects of age, gender and background emotion on 'go'

trial accuracy. This analysis revealed no significant effects. Accuracy on 'go' trials was 98.5% or higher for both groups, in all background conditions, suggesting that performance is at ceiling on this metric for both adolescents and adults.

Go trial reaction time. Reaction times on correct 'go' trials were also analyzed via a 2 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA. This analysis revealed no main effect of group, but did show a main effect of background type ($F(3, 75) = 21.85$, $p < .001$, $\eta^2 = .466$). *Post hoc* comparisons were performed using paired-samples t-tests (two tailed) to compare performance on each background type. These analyses revealed significantly longer reaction times on negative background trials compared to scrambled ($t(28) = 6.45$, $p < .001$), neutral ($t(28) = 6.32$, $p < .001$), and positive ($t(28) = 5.12$, $p < .001$) trials. Reaction times were also found to be significantly faster for scrambled trials versus both positive ($t(28) = 2.79$, $p < .01$) and neutral ($t(28) = 3.19$, $p < .01$) trials. Thus, for the whole sample, responses were significantly faster on scrambled trials and slower on negative trials, relative to trials with positive and neutral background images (see Figure 9).

fMRI Results

Negative versus neutral: Adults only. Because this paradigm has not been previously used in an MRI environment, brain activity in the adult group alone was examined first. In the adult group, a number of frontal and limbic areas were found to be selectively activated during negative blocks compared to neutral blocks (see Figure 10; Table 1). Specifically, the adult group showed greater activity in the medial frontal gyrus (BA 9, left; BA 10, bilateral) and right middle frontal gyrus (BA 8). Limbic areas found

to be differentially activated in this group included left and right amygdala and bilateral nucleus accumbens. In summary, several areas implicated in the processing and regulation of emotion were selectively active for trials with higher levels of emotional distraction (negative background images) as compared to more emotionally neutral trials.

Adults

Region	Side	BA	Talairach Coordinates			t-value	% change
			x	y	Z	df = 11	in signal
Negative > Neutral							
Amygdala/SI	R		24	-4	-7	10.04	0.126
Amygdala/SI	L		-21	-5	-8	9.73	0.148
Middle Frontal Gyrus	R	8	39	11	30	7.88	0.142
Medial Frontal Gyrus	L/R	10	-3	49	-3	5.82	0.191
Nucleus Accumbens	L/R		1	2	3	5.60	0.104
Medial Frontal Gyrus	L	9	-5	47	33	5.51	0.163

Table 1. Areas of activation revealed by a negative versus neutral contrast in adults.

Negative versus neutral blocks: Age-group differences. In order to examine whether the areas selectively engaged on negative relative to neutral trials were different between adults and young adolescents, a direct age group comparison was performed. This analysis revealed several prefrontal regions in which the pattern of activity for negative compared to neutral trials differed between adults and adolescents (see Figure 11; Table 2). These areas included the medial frontal gyrus/frontal eye fields (BA 8, bilateral), right middle frontal gyrus (BA 8 & BA 10), bilateral superior frontal gyri (BA 6) and left middle frontal gyrus (BA 6). In all cases, the difference between negative and neutral blocks was greater (more positive) in the adult group than in the adolescent group. However, an examination of the group means suggests three patterns of activity

difference between groups. In the frontal eye fields (medial BA 8) and premotor cortex (BA 6), adults showed significantly greater BOLD response during negative blocks than during neutral blocks ($t(11) = 3.75$, $p < .005$; $t(11) = 3.38$, $p < .01$; $t(11) = 2.53$, $p < .05$). In contrast, adolescents showed the opposite response, with significantly greater activity during neutral image blocks compared to negative blocks ($t(17) = -2.69$, $p < .05$; $t(17) = -2.24$, $p < .05$; $t(17) = -3.64$, $p < .005$). In contrast, the group difference in right middle frontal gyrus (BA 10) and right superior frontal gyrus (BA 6) were driven by a significant deactivation in the adolescent group ($t(17) = -6.01$, $p < .001$; $t(17) = -4.33$, $p < .001$), while adults showed no significant effect of emotional background in these regions ($t(11) = .558$, $p = .588$; $t(11) = 1.54$, $p = .151$). Finally, another region of right middle frontal cortex (BA 8) demonstrated significant deactivations in both the adult ($t(11) = -2.37$, $p < .05$) and adolescent ($t(17) = -3.14$, $p < .01$) groups. This deactivation was nevertheless significantly greater in the adolescent group than the adult group.

Thus, a number of prefrontal regions, predominantly in anterior and medial areas, were found to be significantly more active in the adult group than the adolescent group during negative blocks compared to neutral blocks. These differences resulted from a combination of activation for negative over neutral blocks in the adult group and deactivation in the adolescent group. None of the areas of interest showed greater activation in the adolescent relative to the adult group.

Contrary to our second hypothesis, this analysis revealed no significant group differences in limbic activity. However, while analysis of the adult group alone did show significant activation of amygdala and nucleus accumbens, when activity on negative blocks was contrasted with activity on neutral blocks, no such effects were observed in

the adolescent group. Thus, there may be some differences in activity in these areas, but high levels of variability in the adolescent data may render these differences nonsignificant in direct group comparisons.

Negative > Neutral

Region	Side	BA	Talairach Coordinates			t-value	% change
			x	y	z	df = 27	in signal
Adults > Adolescents							
Medial Frontal Gyrus	R/L	8	2	33	48	4.63	0.217
Middle Frontal Gyrus	R	10	38	56	11	4.56	0.419
Middle Frontal Gyrus	R	8	46	16	43	4.42	0.324
Superior Frontal Gyrus	L	6	-5	-12	65	4.22	0.283
Superior Frontal Gyrus	R	6	31	6	53	4.12	0.204
Middle Frontal Gyrus	L	6	-29	6	45	3.84	0.138

Table 2. Significant areas of activation for a between age group contrast of negative versus neutral images.

Positive versus neutral blocks: Age-group differences. Though fewer differences in behavioral performance on positive as compared to neutral background trials were observed in the initial behavioral study, age differences in brain activity during positive compared to neutral trial blocks may still exist. Therefore, exploratory analyses examined the group differences in activation (adults vs adolescents) for positive relative to neutral trials. Results revealed several frontal regions in which relative activity for positive versus neutral trials was greater in adults compared to adolescents (see Table 3). These areas included right inferior frontal gyrus (BA 44), right middle frontal (BA6, 8, & 10), and left and right superior frontal gyri (BA 6). In inferior frontal cortex, adults showed significant activation for positive relative to neutral slides ($t(11) =$

3.43, $p < .01$) but adolescents showed no such effect ($t(17) = -1.30$, $p = .213$). Similar effects were seen in two areas of right middle frontal gyrus (BA6 & 8). Like the difference seen in inferior frontal gyrus, activity differences in right BA 6 resulted from significant activation in the adult group ($t(11) = 4.74$, $p < .001$) but no significant effect in the adolescent group ($t(17) = -1.98$, $p = .065$). Likewise, activity in right BA 8 reflected a significant activation for positive relative to neutral in the adult group ($t(11) = 4.60$, $p < .001$) and no significant difference between backgrounds in the adolescent group ($t(17) = -0.81$, $p = .430$). In contrast, activation in right middle frontal gyrus (BA 10) showed opposite effects for the two age groups. The adult group showed stronger activation during positive blocks ($t(11) = 5.27$, $p < .001$), whereas adolescents showed stronger activation during neutral blocks ($t(17) = -3.47$, $p < .005$). Similarily, the group difference in bilateral medial and superior frontal gyri (BA 6) resulted from both activation in the older age group ($t(11) = 3.86$, $p < .005$) and deactivation in the younger age group ($t(17) = -2.64$, $p < .05$).

In contrast to the above results, one area in right middle frontal gyrus (BA 8) revealed a significant group difference in which adolescents showed more activation than adults. Adolescents showed significantly greater activation for positive versus neutral trials ($t(17) = 4.19$, $p < .005$) while adults showed no difference in activation as a function of emotional background ($t(11) = -1.69$, $p = .110$). Overall, the majority of group differences seen in frontal cortex for positive compared to neutral blocks showed greater activation in adults relative to adolescents.

Positive > Neutral

Region	Side	BA	Talairach Coordinates			t-value	% change
			x	Y	z	df = 27	in signal
Adults > Adolescents							
Middle Frontal Gyrus	R	6	43	7	42	5.21	0.201
Medial/Superior Frontal Gyrus	R/L	6	0	-3	55	4.78	0.161
Middle Frontal Gyrus	R	10	30	48	4	4.63	0.202
Middle Frontal Gyrus	R	8	33	13	26	4.34	0.123
Anterior Cingulate Gyrus	R	32	6	25	32	4.19	0.132
Inferior Frontal Gyrus	R	44	53	10	21	3.73	0.177
Adolescents > Adult							
Middle Frontal Gyrus	R	8	43	31	34	-4.66	-0.252

Table 3. Significant areas of activation for a between age group contrast of positive versus neutral images.

The only limbic region to show a difference in activation for postive compared to neutral trials between groups was the right anterior cingulate gyrus (BA 32). In this region, the group difference was generated from a significant activation in the adults ($t(11) = 2.83$, $p < .05$) and a significant deactivation in the adolescents ($t(17) = -2.89$, $p < .05$).

Nogo versus go blocks (Scrambled): Age-group differences. No age group differences in activity were observed in prefrontal cortex or limbic regions for nogo blocks relative to all-go blocks.

Neutral versus scrambled blocks: Age-group differences. Unlike previous group comparisons, the neutral > scrambled block comparison revealed no prefrontal and limbic areas in which adult activation was greater than that for adolescents. It did, however, show a number of frontal brain areas in which adolescents showed greater

activations than adults (see Table 4), including the frontal eye fields (BA 8, bilateral), premotor cortex (BA 6, right), and dorsolateral prefrontal cortex (BA 9, right; BA 46, left).

Neutral > Scrambled

Region	Side	BA	Talairach Coordinates			t-value	% change
			x	y	z	df = 27	in signal
Adolescents > Adult							
Middle Frontal Gyrus	L	46	-40	44	4	-4.82	-0.261
Middle Frontal Gyrus	R	9	45	18	33	-4.40	-0.216
Medial Frontal Gyrus	R/L	8	3	33	47	-4.37	-0.182
Middle Frontal Gyrus	R	6	37	5	41	-3.50	-0.181

Table 4. Significant areas of activation for a between age group contrast of neutral versus scrambled images.

Significant group differences in activity resulted from generally increased activity in the adolescent group (neutral > scrambled) and generally decreased activity in the adults group (neutral < scrambled). In the frontal eye fields and portions of dorsolateral prefrontal cortex, adolescents showed greater activation for neutral compared to scrambled trials ($t(17) = 2.84$, $p < .05$; $t(17) = 3.97$, $p = .001$), but adults showed the opposite effect in these regions ($t(11) = -3.14$, $p < .01$; $t(11) = -2.21$, $p < .05$). In contrast, there were areas of prefrontal cortex than showed sensitivity to background image only in one group. In premotor cortex, adults showed significantly greater activity for scrambled compared to neutral trials ($t(11) = -2.91$, $p < .05$), but adolescents showed no sensitivity to background image in this region ($t(17) = 1.85$, $p = .083$). Similarly, in dorsolateral prefrontal cortex (BA 46), adolescents showed a differential response to neutral

compared to scrambled ($t(17) = 6.24$, $p < .001$), but adults did not ($t(11) = 1.52$, $p = .157$).

In summary, in the neutral greater than scrambled contrast, a group comparison revealed a number of areas in which activation was greater for adolescents than for adults, though group differences resulted from a combination of activations in the adolescent group and deactivations in the adult group.

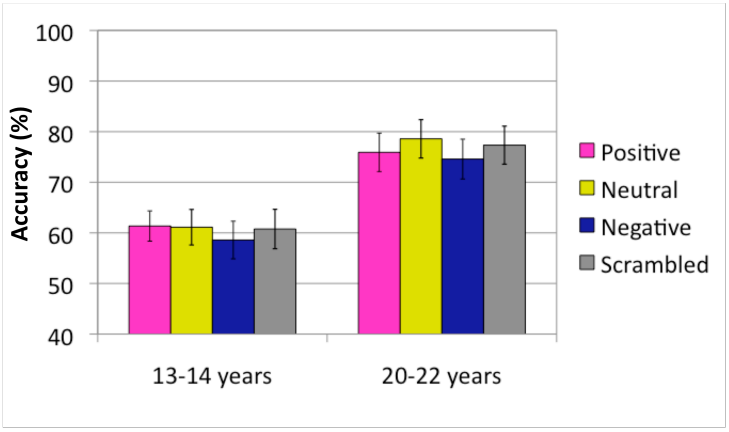

Figure 8. Accuracy on nogo trials for each age group and background type.

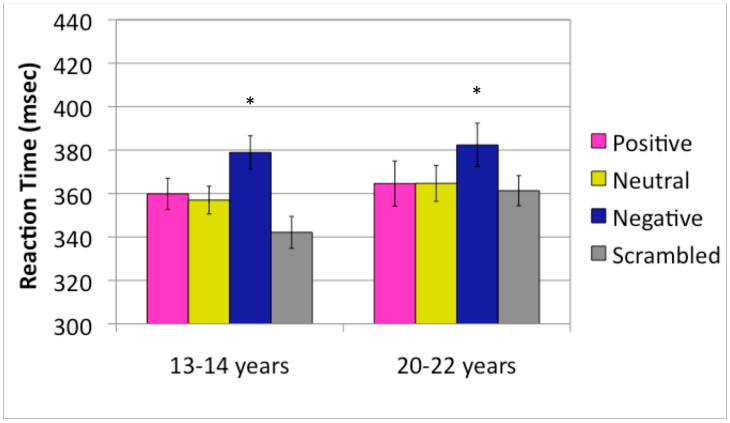

Figure 9. Reaction times on correct go trials for each age group and background.

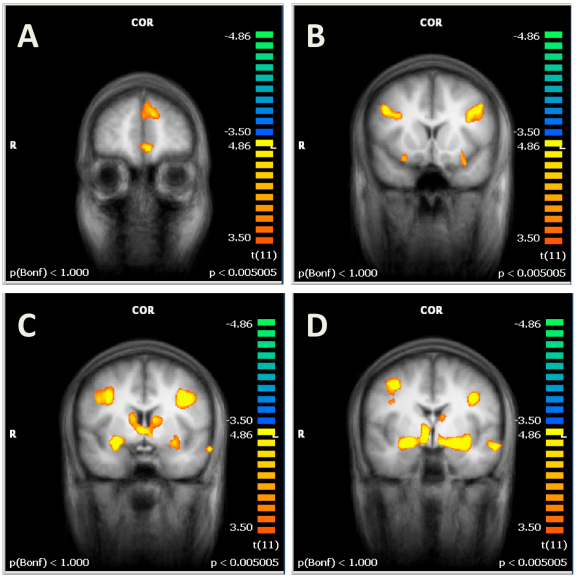

Figure 10. Activated regions for negative > neutral in the adult group: a) left and bilateral medial frontal gyrus, BA 9/10; b) middle frontal gyrus, BA8; c) bilateral nucleus accumbens; d) bilateral amygdala/substantia innominata (SI)

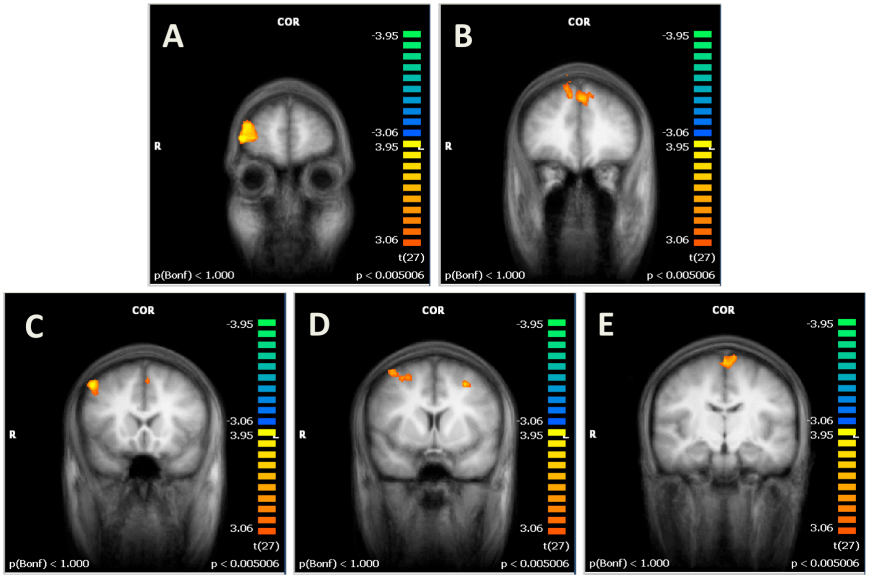

Figure 11. Activated regions in adults > adolescents for a contrast of negative versus neutral blocks: a) right middle frontal gyrus, BA 10; b) bilateral medial frontal gyrus, BA 8; c) right middle frontal gyrus, BA 8; d) right superior frontal gyrus, BA6, and left middle frontal gyrus, BA 6; e) left superior frontal gyrus, BA 6.

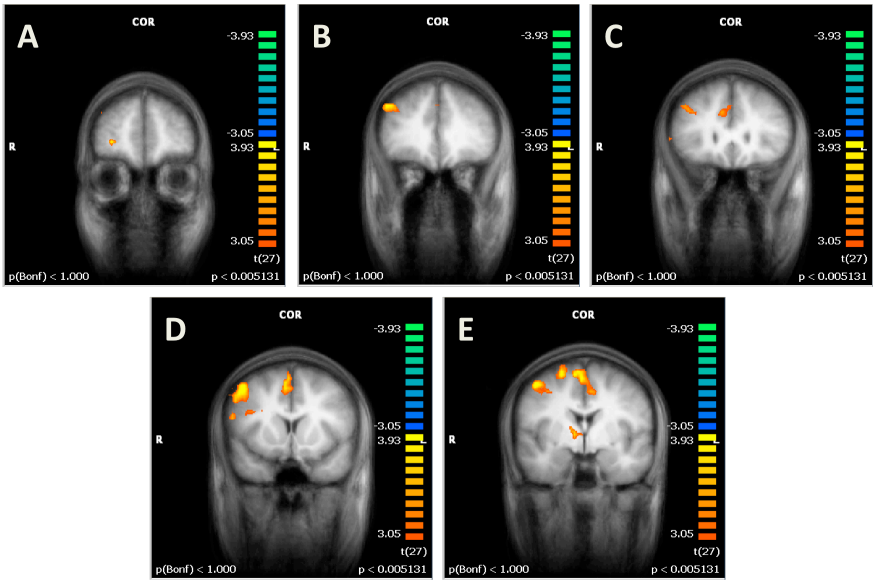

Figure 12. Activated regions in an age group comparison for a contrast of positive versus neutral blocks: a) right middle frontal gyrus, BA 10 (adult > adolescent); b) right middle frontal gyrus, BA 8 (adolescent > adult); c) right anterior cingulate, BA 32; d) right middle frontal gyrus, BA 6, right middle frontal gyrus, BA 8 (adult > adolescent); e) bilateral medial/superior frontal gyrus, BA 6, right inferior frontal gyrus, BA44 (adult > adolescent).

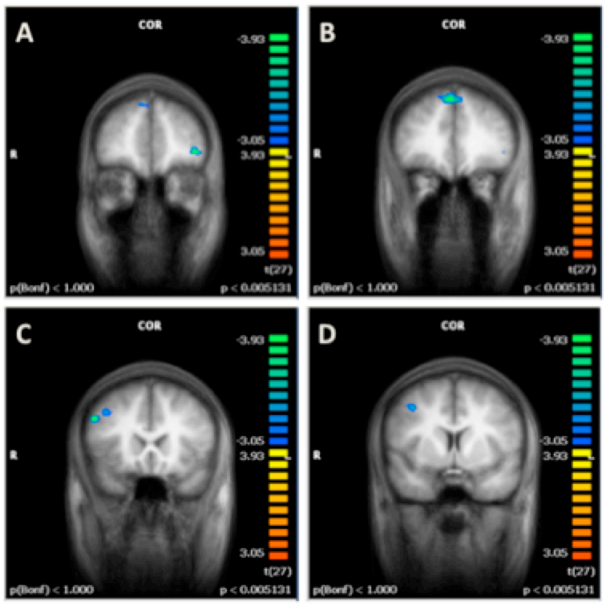

Figure 13. Activated regions in adolescents > adults for a contrast of neutral versus scrambled blocks: a) left middle frontal gyrus, BA 46; b) bilateral medial frontal gyrus, BA 8; c) right middle frontal gyrus, BA 9; d) right middle frontal gyrus, BA 6.

Discussion

This study found significant differences in nogo trial accuracy between adults and adolescents, supporting the prediction that inhibitory control would improve with age during the second decade of life. As in the previous behavioral study (see chapter 1), no age differences in response time were found. Both age groups showed a main effect of trial background on reaction time, with negative images slowing reaction times relative to all other background types and scrambled backgrounds associated with the fastest responses in both age groups. While main effects of age and background were replicated from the initial behavioral study, no age by background interaction was found in this sample. This difference is likely largely due to the effect of the scanner environment. Demands of the scanner environment, including physical space constraints, loud mechanical noise, supine body position, and restricted physical movement likely contribute to an overall drop in accuracy in both age groups (relative to performance in the behavioral task). In addition, it is possible that participants show heightened anxiety in the scanner environment relative to the standard laboratory environment, which may alter response to emotional stimuli and may have washed out accuracy differences for different background types.

Imaging results of this study indicate that significant age differences do exist in recruitment of prefrontal cortex during a task that requires participants to ignore irrelevant emotional information, whether that information is positively or negatively valenced. No differences were found in prefrontal cortex, however, for basic inhibitory control (go-nogo versus all-go) between groups. This may be due to the use of a block

design that did not allow for the direct comparison of go and nogo trials, but rather contrasted blocks that either contained or did not contain inhibitory trials. That is, even inhibitory blocks consisted of more go than nogo trials, as is needed for participants to acquire a prepotent tendency to press. Thus, activation of anterior cingulate or ventral prefrontal areas associated with inhibitory control and response monitoring may not have reached our significance threshold when activity was averaged across the entire block. Future studies using event-related fMRI paradigms may more readily show these effects. However, limitations on the rate of stimulus presentation would need to be resolved in order for a challenging go-nogo paradigm to be implemented during event-related fMRI recording.

When negative and neutral trials were compared in the adult group alone, significant activation was seen, as predicted, in both prefrontal and limbic brain areas (amygdala, cingulate cortex, and nucleus accumbens). Surprisingly, no selective activation in orbitofrontal cortex was observed despite previous literature implicating this region in regulation of emotional responses. Furthermore, when activation during negative and neutral blocks was compared between groups, differential activation was not observed in any limbic regions. This lack of difference may be due to greater variability in responding within the adolescent group resulting in subthreshold activity in this group. However, this result is nevertheless quite different from those found by Hare et al. (2008), who reported significantly greater activation in amygdala in adolescents compared to both children and adults during performance of an emotional go-nogo task. This difference could be due to the difference in task requirements to either attend, as in the Hare study, or ignore, as in the current study, the emotional information. Monk et al.

(2003) also reported greater amygdala activation in adolescents versus adults when participants were instructed to attend to a non-emotional aspect of the stimuli (nose width). One difference between the current research and these two prior studies is the use of IAPS images instead of face stimuli. It is conceivable that while adolescents are particularly reactive to negative facial expressions of emotion, they do not respond as powerfully to all forms of emotionally negative information. In fact, many of the challenges of adolescence relate to social functioning and it is possible that social cues are therefore particularly salient. Alternatively, it is possible that adolescents are activating the amygdala indiscriminately for all background image types and therefore show no significant differences among them.

Unlike the contrasts of negative and positive blocks against neutral block, when the neutral versus scrambled contrast was compared between groups, several prefrontal regions were activated more strongly by the adolescent than the adult group. This finding supports the suggestion that adolescents tended to recruit prefrontal cortex in the presence of any distracting image, even if its emotional content was relatively neutral, while adults recruited more selectively when emotionally salient images created a higher level of attentional conflict. In fact, several of the regions revealed in the group contrasts of negative versus neutral and positive versus neutral were driven, at least in part by significant deactivation in the adolescent group. That is, the adolescent group was showing selective activation for neutral over negative and positive conditions. This difference may be driven by the higher degree of ambiguity in the neutral scenes, but this interpretation is purely speculative. As previously discussed, behavioral results did not

suggest increased attention to neutral scenes in adolescents relative to adults, as indicated by either increased errors or slowed reaction times on neutral blocks.

Future studies may benefit from including a passive image viewing condition such that brain responses to images alone and in the context of the inhibitory control task may be more readily teased apart. No fMRI studies to date have examined adolescent brain activation during passive viewing of the IAPS slides.

Chapter 3: Response Inhibition and Working Memory During Emotional Distraction in Adolescence

While the preceding chapters begin to shed light on the interaction between emotion and inhibitory control across adolescence, they have not addressed whether this relationship can be generalized to other forms of executive function or if it is specific to response inhibition. Adolescent development of prefrontal cortex is likely critical to more than one form of executive function. Other important functions include task switching, planning and working memory. Each of these cognitive skills plays a valuable role in regulating cognition and behavior and contributes to everyday functioning in both emotional and unemotional situations. However, the introduction of emotional content may interact differently with different form of executive function. In order to explore this question, in this study adolescents and young adults were asked to perform a task that measured the effects of emotional background images (IAPS slides) on a working memory task: the n-back. This task was modeled after that used by Ladouceur et al. (2005) to study adolescents with anxiety and major depression, as well as healthy controls.

As described in the introduction, the n-back task requires participants to continually update the contents of working memory. Stimuli are presented briefly, one at a time, and participants are asked to respond to each letter presented, indicating whether or not the letter just presented is the same as the one presented 'n' trials back in the sequence. Difficulty can be readily manipulated by changing the value of n and thus the number of letters that must be maintained in memory at any given time.

Participants in this sample again ranged between age 11 and 25, as in the original go-nogo study. However, given the absence of differences between the 18-19 and 20-25 year-old groups seen in chapter one, these groups were combined in the current study. In addition to completing the n-back task, participants in the current study completed a shortened version of the original go-nogo task and also provided subjective ratings, at the end of the session, of some of the background images seen during the two executive tasks. Including the go-nogo task in this study allowed for the within-subject comparison of performance on the two distinct executive tasks as well as exploration of the influence of emotional distraction on each. Subjective ratings of the background images were used to determine whether major differences in subjective experience of the images existed between age groups and thus to begin to establish whether accuracy differences between groups were due to differences in cognitive control, differences in emotional response to the background images, or a combination of both.

Method

Participants

Ninety-eight healthy participants between the ages of 11 and 25 were included in this sample. Participants were grouped into four age groups: 11-12 years (25 participants, 12 male, mean age = 12.1 years), 13-14 years (25 participants, 12 male, mean age = 14.1 years), 15-16 years (24 participants, 11 male, mean age = 15.9 years), and 20-25 years (24 participants, 12 males, mean age = 21.7 years). Adult participants were recruited from the undergraduate population of the University of Minnesota. Adolescents were recruited from a database of local families maintained by the Institute

of Child Development at the University of Minnesota. Participants were paid for their participation and parents were compensated for travel expenses. All participants were screened for self-reported neurological and psychological disorders as well as serious medical issues and learning disabilities. Participants were excluded from the study if they had previously participated in a study using the behavioral task. While at the lab, participants completed a series of standardized questionnaires that probe anxiety levels (STAI for adults and STAI-C for adolescents), attention skills (CAARS for adults and Conner's Parent Rating Scale for adolescents) and general functioning (SCL-90 for adults and the Achenbach CBCL and YSR for adolescents). Participants who scored within the clinical range on selected scales were removed from subsequent data analyses. Adults were excluded if they scored in the clinical range for any of the following scales on the SCL-90: depression, anxiety, phobic anxiety, paranoid ideation, and psychoticism. Adult participants were also excluded from analysis for clinical range scores on either state or trait anxiety measures, as assessed by the STAI, or on the cognitive, hyperactivity, or ADHD scales of the CAARS. Adolescent participants were excluded from analysis if responses on either the YSR or CBCL were within the clinical range for the following scales: anxious/depressed, withdrawn/depressed, thought problems, attention problems, affective problems, anxiety problems, and attention deficit/hyperactivity problems. Adolescents were also excluded for scoring in the clinical range for either state or trait anxiety on the STAI-C or for any of the cognitive, hyperactivity or ADHD scales on the Conner's Parent Rating Scale. In addition to the 98 participants included in analysis, 19 participants were tested then excluded from analysis based on their responses on the questionnaires. Two males and three females were excluded from the 11-12 year-old

group, one male was excluded from the 13-14 year-old group, five males were excluded from the 15-16 year-old group, and seven males and one female were removed from analysis in the 20-25 year-old group.

Behavioral Tasks

In experiment three, the 360 IAPS images used in the previously described experiments were split into two groups of 180 images, to be used as backgrounds for two cognitive tasks designed to tap executive function: a go-nogo inhibitory control task and an n-back working memory task. Images for each set were selected to balance content and valence ratings between the sets as much as possible. Average valence ratings were identical for the two sets: negative = 3.2, positive = 7.4, and neutral = 5.3. Average arousal ratings were also closely matched: negative = (1) 5.3, (2) 5.2; positive = (1) 5.0, (2) 5.0; neutral = (1) 3.2, (2) 3.4. However, to control for any remaining differences between the image sets, these sets were counterbalanced across tasks. To limit habituation effects, each individual IAPS image was presented only once to any given participant. Thus, if a given image set were used during the n-back, the other set would always be used during the go-nogo task for that same participant. Each session consisted of the two tasks, presented in a counterbalanced order, followed by subjective image ratings. Ratings were always collected at the end of the session in order to ensure that images were seen for the first time during the behavioral tasks. All tasks were presented on a 16" monitor. During task completion, all participants were asked to wear two sensors on their torso for the recording of heart rate, and four sensors on their non-dominant hand for the recording of galvanic skin responses. While the autonomic data

will not be described in the current document, the wearing of the sensors required participants to hold their non-dominant hand and torso quite still during recording, which may have indirectly increased the self-regulation demands of both tasks.

Go-nogo task. The go-nogo task used was a shortened version of the original IAPS go-nogo task described in chapter one. In this version, each of the runs consisted of 60 trials instead of the original 120. Runs were administered in the same order as in the original task: one scrambled-background run, followed by three emotional-background runs, and then a second scrambled run. Emotion slides were again grouped into blocks of twenty slides of the same valence (positive, negative, or neutral) to control for individual differences in response to particular images. Each emotion run consisted of one block of each valence, presented in a randomized order. Order of stimulus presentation and timing within a trial were equivalent to the original study (see Figure 1). As before, participants were instructed to press the space bar as quickly as possible in response to all letters appearing on the screen, with the exception of the letter X. Measures of interest included accuracy on nogo trials and reaction time on correct go trials. Go trial accuracy was also analyzed in order to check for group differences in sustained attention.

N-back task. As in the go-nogo, the n-back task consisted of a series of sequentially presented letters in a small white box at the center of a larger background image. While the visual stimuli were very similar to those used in the go-nogo, task instructions were quite different. The n-back task included three different memory conditions: 1) a 0-back condition in which the target was the letter X; 2) a 2-back condition in which targets were letters that matched the one presented two trials prior in the sequence (e.g. C-B-C); and 3) a 3-back condition in which targets were letters that

matched the one presented three trials prior in the sequence (e.g. C-B-T-C). Participants were asked to press the 2 key for target trials and the 1 key for all other trials. The inclusion of a 0-back condition, which has a relatively small working memory component, served as a control for differences in performance based on differences in sustained attention. The 3-back was included in order to prevent ceiling effects in the older participant groups and to explore effects of increased memory load on performance.

Each trial began with a fixation cross on a grey background presented for 500 ms. This was followed by an IAPS image presented for 350 ms before the target letter appeared in a small white box (.04" x .04") in the center of the background image. The letter remained on the screen for 500 ms. The image alone then remained on the screen for 1500 ms, during which time the participant had the opportunity to respond. Each full trial was 3000 ms in duration. Trial structure is depicted in Figure 14. Target trials (i.e. repeated letters or the letter X in the 0-back condition) occurred four times within any given block of 20 trials. Letters used in this paradigm included B, C, F, H, P, Q, S, T and X. The first nine letters occurred twice in any given block while the X appeared four times, generating four target trials in the 0-back condition as well as in the memory conditions while the letter stimuli presented were kept consistent in each block.

The emotional n-back was presented in three runs. Each run included 60 trials, divided into blocks of 20 trials. After each 20-trial block, the participant received new on-screen instructions, indicating which memory rule he/she should use in the subsequent block (0-back, 2-back, or 3-back). The mixing of memory conditions across blocks was intended to prevent practice effects sometimes seen in executive tasks with sustained performance on a single set of instructions. Each 20-trial block presented slides from a single valence

category (positive, negative, or neutral). The order of memory condition and emotion blocks was distributed such that each run contained one 20-trial block of each memory condition and each emotion category. The order in which emotions and memory conditions were presented was counterbalanced across runs.

In order to control for group differences in practice and fatigue, runs consisting of 60 trials with scrambled image backgrounds occurred both before and after the emotion runs. Each scrambled run had three blocks, one of each memory load (0-back, 2-back, 3-back). Because of the complexity of the task, prior to beginning the task, researchers walked participants through two practice cards (one each for the 2-back and 3-back conditions) and had participants complete a brief practice round (12 trials of each memory condition, presented on a plain, black background) in order to ensure that all participants understood the task prior to the first run of scrambled trials.

Figure 14. Example of a set of 2-back trials. The target trial occurs when a letter repeats after two trials (one intervening letter).

Data Analysis of Go-nogo and N-back Tasks

For the go-nogo task, the outcome variables of interest were accuracy on nogo trials, accuracy go trials, and reaction times on correct go trials. In the n-back task, accuracy scores on target and non-target trials were analyzed separately, as well as reaction times on correct trials. Each of these outcome variables was analyzed via mixed-model ANOVAs including age group (11-12, 13-14, 15-16, 18-25 years) and gender as between-subject factors and trial background type (negative, positive, neutral, scrambled) as a within subject factor. Greenhouse-Geisser corrections were used to adjust results in analyses of datasets that violated the assumption of sphericity (Mauchly's test, $p < .05$). Significant effects of age group were followed up with Bonferroni-corrected *post hoc* comparisons. Significant effects of background were followed up using two-tailed paired-samples t-tests.

Supported by the go-nogo results described in chapter one, it was again hypothesized that adolescent groups would show diminished accuracy, and possibly increased reaction times on negative and/or positive trials, relative to neutral and scrambled trials, while performance in the older groups would be less disrupted by emotional distractions. Therefore, ANOVAs examining the effect of background content were performed for each age group separately, even in cases where a significant age group x background effect was not found. Results of these ANOVAs were followed up using paired samples t-test (two-tailed) comparing performance on the four background types in order to determine what types of background information was disruptive at different ages.

In the n-back task, insufficient trial numbers were available to examine target reaction times by age group, gender, background and memory load. Therefore two separate analyses were conducted. The first examined effects of image background regardless of memory load. The second examined effects of memory load while collapsing across all image backgrounds.

Subjective Ratings of IAPS Images

After completing both the go-nogo and n-back tasks, participants were asked to subjectively rate a selection of 30 of the IAPS images that had been used as backgrounds during the preceding tasks. Slides were rated on two scales – valence and arousal – using the Self Assessment Manikin (SAM) scale developed by Lang, Bradley, and Cuthbert (2001). The SAM scale requires that participants choose which of a series of nine figures best represents how the image made them feel. The figurines correspond to a 9-point scale. In the valence scale, ratings range from 1 = highly negative to 9 = highly positive, with 5 representing a neither positive nor negative emotional reaction. In the arousal scale, ratings range from 1 = not at all arousing, to 9 = highly arousing. Though the original administration of the SAM scale was a paper and pencil test, for facility of data processing, the SAM scale was presented on the computer. Participants were familiarized with the two scales prior to beginning the rating process. During the rating procedure, images were presented onscreen for 6 seconds, during which time participants were instructed to look at the picture and feel whatever emotional response the image naturally evoked. After the image left the screen the valence scale manikins were then presented onscreen with numbers from one to nine presented below each figure. Ratings

were indicated by pressing the number key corresponding to the chosen figure. After a selection had been made for the valence scale, the arousal scale appeared onscreen. After the participant had entered their rating on the arousal scale, a new image was then presented. Because of time restrictions, subjective ratings were not collected for each of the IAPS images for every participant. IAPS images were subdivided such that each participant rated ten IAPS images from each valence category (positive, negative and neutral). Presentation of images was balanced such that every image used as a background was rated by at least on male and one female in each age group. For analysis, average negative, positive, and neutral ratings were obtained for each group on both the valence and arousal scales. These average measures were then compared between groups.

Results

Go-NoGo Task

Nogo trial accuracy. Mean nogo trial accuracy across age groups and background types is summarized in Figure 15. A 4 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA revealed main effects of background ($F(3, 270) = 7.77$, $p < .001$, $\eta^2 = .079$) and age group ($F(3, 90) = 25.82$, $p < .001$, $\eta^2 = .463$), as well as a trend-level group x gender interaction ($F(1, 90) = 2.36$, $p = .077$, $\eta^2 = .073$). The main effect of group was followed up via *post hoc* contrasts, revealing significantly lower nogo accuracy in the 11-12 year-old group relative to all three older groups ($p < .001$ in each case). This analysis also found significantly lower accuracy scores in the 13-14 year-old group when compared to adults ($p < .001$) as well as significantly lower accuracy in the

15-16 year-old group relative to adults ($p = .05$). Thus, in this sample, nogo accuracy improves throughout the teen years.

The main effect of background was explored further via paired samples t-tests. Accuracy on negative trials was found to be significantly lower relative to scrambled ($t(97) = 4.99$, $p < .001$), neutral ($t(97) = 2.84$, $p = .01$), and positive ($t(97) = 2.50$, $p < .05$) trials. Accuracy was also lower on positive relative to scrambled trials ($t(97) = 2.51$, $p < .05$) and a trend was found for accuracy on neutral trials to likewise be lower than on scrambled trials ($t(97) = 1.96$, $p = .053$).

Based on the previous findings that the influence of slide backgrounds on nogo accuracy may be influenced by both age group and gender, a 2 (gender) x 4 (background: negative, positive, neutral, scrambled) mixed-model ANOVA was performed for each age group individually despite the lack of interaction in the overall ANOVA. Results revealed a main effect of trial background in only the 11-12 year-old group ($F(3, 69) = 5.11$, $p < .01$, $\eta^2 = .182$). In this same age group, a significant main effect of gender was found, with females (mean = 63.85, sd = 3.89) outperforming males (mean = 50.04, sd = 3.89) in nogo trial accuracy. Mean accuracy for each gender, age group and background type is presented in Figure 16.

Despite the lack of a significant interaction between background and age group, in order to further explore the influence of emotional and non-emotional backgrounds on response inhibition at different points in adolescence, paired sample t-tests were used to compare accuracy on each background type in each age group. The 11-12 year-old group showed significantly lower accuracy scores on negative trials compared to scrambled ($t(24) = 4.27$, $p < .001$), neutral ($t(24) = 2.07$, $p < .05$), and positive ($t(24) =$

2.42, $p < .05$) trials. Accuracy in this group was also found to be significantly lower on positive versus neutral trials ($t(24) = 1.91$, $p < .05$). In contrast to experiment one, the 13-14 year-old group showed no significant effects of background on nogo trial accuracy. T-tests did, however, reveal trends for negative trial accuracy to be lower vis-à-vis scrambled ($t(24) = 2.00$, $p = .056$) and positive ($t(24) = 1.90$, $p = .069$) trials in this age group. The 15-16 year-old group showed a trend for lower accuracy on negative trials relative to neutral ones ($t(23) = 1.97$, $p = .060$). While the oldest age group (18-25 years) did not show lower accuracy on negative relative to other trial types, this group did show significantly lower accuracy on neutral compared to scrambled trials ($t(23) = 2.34$, $p < .05$).

Runs one and three (scrambled trials only) were compared in order to test for practice or fatigue effects, using a 4 (age group) x 2 (gender) x 2 (run: 1 vs. 3) mixed-model ANOVA. Results revealed a main effect of group ($F(3, 90) = 18.36$, $p < .001$, $\eta^2 = .380$) as well as a group x run interaction ($F(1, 90) = 2.70$, $p = .05$, $\eta^2 = .083$). *Post hoc* contrasts comparing nogo accuracy in each group found that accuracy was significantly lower in the youngest group relative to the 13-14 year-old group ($p < .05$), the 15-16 year-old group ($p < .001$) and the 18-25 year-old group ($p < .001$). The 13-14 year-old group also showed significantly lower accuracy than the young adults ($p < .001$). Despite the significant group x run interaction, paired sample t-tests (two tailed), revealed no significant effects of run in any group, when analyzed separately.

Go trial accuracy. As in previous studies, go trial accuracy was not considered a central measure of inhibitory control, but was nevertheless analyzed as a potential index of sustained attention. Thus, a 4 (age group) x 2 (gender) x 4 (background) mixed-model

ANOVA was performed with go trial accuracy as the dependent measure. Results revealed main effects of background ($F(2.3, 205) = 7.94$, $p < .001$, $\eta^2 = .081$), group ($F(3, 90) = 5.69$, $p = .001$, $\eta^2 = .159$) and gender ($F(1, 90) = 3.95$, $p = .05$, $\eta^2 = .042$). The ANOVA also revealed a trend-level interaction between background and group ($F(6.8, 205) = 1.99$, $p = .060$, $\eta^2 = .062$). Mean go trial accuracy for each age group and background type are presented in Figure 17.

The main effect of group was followed up with *post hoc* contrasts, comparing go trial accuracy between groups. These contrasts revealed significantly lower accuracy scores in the 11-12 year-old group relative to the 15-16 year-old group ($p < .01$) and the 18-25 year-old group ($p < .01$). There was also a trend for the youngest group to perform more poorly than the 13-14 year-old group ($p = .056$). The main effect of background was followed up with paired-sample t-tests comparing go trial accuracy on each background type. This analysis revealed lower accuracy on negative versus scrambled ($t(97) = 3.11$, $p < .01$), neutral ($t(97) = 3.34$, $p = .001$), and positive ($t(97) = 4.01$, $p < .001$) trials. The main effect of gender was due to slightly higher accuracy in the male participants (mean accuracy = 99.1%, sd = 1.2%) than the female participants (mean accuracy = 98.4%, sd = 2.1%), although both genders appear to be performing close to ceiling.

The group x background interaction was followed up with repeated measures ANOVAs comparing performance across the four background types within each age group. The analysis showed only one significant effect of background type, in the 11-12 year-old group ($F(1.6, 37.3) = 5.66$, $p = .01$, $\eta^2 = .198$). There was no significant effect of background in the other age groups, suggesting that the background content may have

been most disruptive to the youngest group in terms of pressing for all go stimuli. Paired samples t-tests revealed that this group had lower go trial accuracy on negative versus scrambled ($t(24) = 2.86$, $p < .01$), neutral ($t(24) = 2.53$, $p < .05$), and positive ($t(24) = 3.66$, $p = .001$) trials, paralleling the findings for nogo trial accuracy in this group.

A 4 (age group) x 2 (gender) x 2 (run: 1 vs. 3) mixed-model ANOVA was run in order to assess age or gender differences in fatigue or practice effects. Results showed only a main effect of group ($F(3, 90) = 4.62$, $p = .005$, $\eta^2 = .133$). As for the overall go trial accuracy results, group differences were found between the 11-12 year-old group and both the 15-16 year-old group ($p < .01$) and the 18-25 year-old group ($p < .05$). Thus, group differences computed for the scrambled trials alone were similar to those found for all trial types together.

Go trial reaction time. Mean reaction times for all age groups and background types are presented in Figure 18. Like, go accuracy scores, reaction times on correct go trials were analyzed using a 4 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA. This analysis revealed main effects of background ($F(3, 270) = 30.24$, $p < .001$, $\eta^2 = .251$) and gender ($F(1, 90) = 11.06$, $p = .001$, $\eta^2 = .109$). No effect of age group on go trial reaction time was observed. There were also no significant interaction effects. The main effect of gender was due to females (mean rt = 399.40 ms, sd = 40.43ms) responding, on average, significantly slower than males (mean rt = 373.56ms, sd = 36.74ms). Paired sample t-tests were performed to compare reaction times in the four different background conditions. As seen previously, reaction times for negative trials were significantly slower than for scrambled ($t(97) = 2.08$, $p < .05$), neutral ($t(97) =$

7.69, $p < .001$), and positive ($t(97) = 5.37$, $p < .001$) trials. Responses for positive background trials were also significantly slower than for both scrambled ($t(97) = 4.26$, $p < .001$) and neutral ($t(97) = 7.96$, $p < .001$) trials. Neutral trial reaction times were, in turn, significantly longer than those for scrambled trials ($t(97) = 2.12$, $p < .05$). Thus, reaction times in this sample reflect the predicted pattern in which scrambled trials are least distracting and evoke fast responses. Responses then slow with the introduction of recognizable image content (neutral trials) and then with the addition of emotional information (positive and negative trials), with negative trials being the most disruptive to rapid responding.

Paired t-tests were used to compare reaction times on different background types in each age group. The 11-12 year-old group showed significantly slower reaction times on negative versus scrambled ($t(24) = 3.57$, $p < .01$) and neutral ($t(24) = 6.31$, $p < .001$) trials, but not positive trials ($p = .108$). This group also had significantly slower reaction times on positive trials relative to both scrambled ($t(24) = 2.50$, $p < .05$) and neutral ($t(24) = 2.86$, $p < .01$) trials. Thus, the youngest group was slowed by both positive and negative emotional information to a similar degree. The 13-14 year-old group showed significantly slower reaction times on negative versus scrambled ($t(24) = 6.33$, $p < .001$), neutral ($t(24) = 3.39$, $p < .01$) and positive ($t(24) = 4.57$, $p < .001$) trials. In this age group, scrambled trials, in addition to having faster reaction times than negative trials, were also significantly faster than positive ($t(24) = 2.43$, $p . < .05$) and neutral ($t(24) = 2.46$, $p < .05$) trials. The 15-16 year-old group showed only one significant difference in reaction time between trial types: responses on negative trials were significantly longer than those on scrambled trials ($t(23) = 2.28$, $p < .05$). There was also a trend for

responses on negative trials to be slower than on neutral trials ($t(23) = 1.99$, $p = .058$). In the oldest group, negative trials were again the slowest compared to all three other trial types: scrambled ($t(23) = 4.84$, $p < .001$), neutral ($t(23) = 4.30$, $p < .001$) and positive ($t(23) = 3.18$, $p < .01$). There was also a smaller effect of positive trials having longer reaction times relative to scrambled trials ($t(23) = 2.60$, $p < .05$). In summary, each group's negative trials had the slowest reaction times while scrambled trials were consistently fastest. The response time for positive and neutral trials, in relation to other trial types, appeared to change with age.

Practice and fatigue effects for each age group and gender were evaluated via a 4 (age group) x 2 (gender) x 2 (run: 1 vs 3) mixed model ANOVA, looking at the scrambled trial runs that appeared at the beginning and end of the task. This analysis of scrambled trials only revealed a main effect of gender ($F(1, 90) = 9.58$, $p < .005$, $\eta^2 = .096$) with females responding significantly more slowly than males (females: mean rt = 389.15ms, sd = 5.44ms; males: mean rt = 366.33ms, sd= 4.87ms). This analysis revealed no other significant effects, suggesting than any age differences in fatigue or practice effects were not reflected in go trial reaction time measures.

N-Back Task

Target accuracy: 0-back (X) trials. Mean target accuracy in the 0-back condition for each age group and background type is presented in Figure 19. Accuracy on target trials (Xs) in the 0-back, non-memory condition was analyzed via a 4 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA. Significant main effects of both background ($F(2.5, 219) = 3.90$, $p < .05$, $\eta^2 = .042$) and age group ($F(3, 88) = 5.72$, p

= .001, η^2 = .163) were found. There were, however, no significant interaction effects. The main effect of age group was followed up via *post hoc* contrasts. Significantly worse performance was found in the youngest group (11-12 years) relative to the three older groups: 13-14 years ($p < .05$), 15-16 years ($p < .01$), and 18-25 years ($p < .01$). No other group differences reached significance. The effect of background on accurate target detection in the full sample was explored via paired-samples t-tests. Accuracy on target (X) trials was found to be significantly lower on positive trials relative to both scrambled ($t(95) = 2.20$, $p < .05$) and neutral ($t(95) = 2.74$, $p < .01$) trials. Accuracy on negative trials, however, was only lower, at a trend level in comparison to neutral trials ($t(95) = 1.88$, $p = .063$). This finding was clearly distinct from the pattern established in the go-nogo results, in which negative backgrounds were consistently the most disruptive to performance.

In order to follow up the prediction that the influence of background on performance may vary by age, separate repeated measures ANOVAs were performed to determine the influence of background content in each of the four age groups. Results revealed a significant effect of background in the 11-12 year-old group. Follow-up paired-samples t-tests confirmed that significant differences in performance based on background appeared only in the youngest age group and reflected the pattern observed in the overall results. That is, accuracy was lower for positive trials compared to neutral ($t(95) = 2.70$, $p < .05$) and scrambled ($t(95) = 2.23$, $p < .05$) trials and accuracy on negative trials was lower, at a trend level, than neutral trials only ($t(23) = 2.01$, $p = .057$).

In order to assess the influence of age and gender on practice or fatigue effects, a 4 (age group) x 2 (gender) x 2 (run: 1 vs. 3) mixed model ANOVA was run. Results

showed significant main effects of both run ($F(1, 88) = 7.93$, $p < .01$, $\eta^2 = .083$) and gender ($F(1, 88) = 7.14$, $p < .01$, $\eta^2 = .075$), as well as a significant three way run x age group x gender interaction ($F(3, 88) = 2.73$, $p < .05$, $\eta^2 = .085$). Overall accuracy declined between run one (mean accuracy = 96.4%, sd = 10.25%) and three (mean accuracy = 91.15%, sd = 16.21%). Males, on average, also significantly outperformed females on this task metric (female mean = 91.42%, sd = 10.68%; male mean = 96.57%, sd = 7.61%).

The three-way run x age group x gender interaction effect was followed up with mixed-model 2 (gender) x 2 (run: 1 vs. 3) ANOVAs conducted within each age group. When evaluated separately, only the 15-16 year-old group demonstrated a significant effect of gender ($F(1, 22) = 5.83$, $p < .05$, $\eta^2 = .210$), though this may be partly due to the absence of variance in the male group (female mean = 91.54 %, sd = 3.24%; male mean = 100%, sd = 0%). All other significant effects were seen only in the 18-25 year-old age group. In this group, accuracy declined significantly between the first and last run ($F(1, 22) = 5.50$, $p < .05$, $\eta^2 = .200$; run 1 mean = 98.96 %, sd = 5.10%; run 3 mean = 90.63 %, sd = 17.78%). However, the ANOVA also showed a significant run x gender interaction driven by the fact that while males showed no change in accuracy between run 1 and 3 (males: run 1 mean = 97.92%, sd = 7.21%; run 3 mean = 97.92%, sd = 7.21%), performance in the oldest female group declined significantly (females: run 1 mean = 100%, sd = 0%; run 3 mean = 83.33%, sd = 22.19%). However, performance in the 18-25 year-old females in run 3 is highly variable and it is likely that not all participants in this group showed this decline in accuracy across the course of the task.

Target accuracy: 2-back memory trials. Two-back target-trial accuracy means for each age group and background are presented in Figure 20. The ability to correctly identify letters seen two trials back in a sequence was analyzed using a 4 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA. Results revealed main effects of age group ($F(3, 88) = 5.63$, $p = .001$, $\eta^2 = .161$) and background ($F(3, 264) = 3.02$, $p < .05$, $\eta^2 = .033$). The effect of age group was further analyzed via *post-hoc* contrasts, revealing a significant difference between the youngest (11-12 years) and oldest (18-25 years) groups ($p = .001$) as well as a trend level difference between the 11-12 year-old group and the 15-16 year-old group ($p = .054$).

The main effect of background was followed up via paired-samples t-tests. Significantly higher accuracy on match trials in the 2-back memory condition was found for scrambled trials compared to positive ($t(95) = 2.24$, $p < .05$) and negative ($t(95) = 2.76$, $p < .01$) background trials. A trend level effect was also seen between performance on negative and neutral trials ($t(95) = 1.88$, $p = .063$), with lower accuracy in the presence of the negative background images.

Despite the lack of a significant age group x background interaction, in order to further explore the *a priori* hypothesis that effects of background would vary by age group, paired-samples t-tests, were used to compare accuracy on the four background types in each age group. Only one significant effect emerged from these comparisons: in the 15-16 year-old group, accuracy on negative trials was significantly lower than on scrambled trials ($t(23) = 2.46$, $p < .05$). At a trend level, in the 13-14 year-old group, performance on positive trials was found to be poorer than on scrambled trials ($t(23) =$

2.02, p = .055). No other effects of background were found within the individual age groups.

A 4 (age group) x 2 (gender) x 2 (run: 1 vs. 3) mixed model ANOVA revealed no main effect of run or interaction effects, suggesting that practice and fatigue effects were not significant in this sample for this measure, or significantly different between groups. A main effect of group ($F(3, 88) = 3.23$, $p < .05$, $\eta^2 = .099$) was produced by a significant difference in accuracy on scrambled trials between the youngest (11-12 years) and oldest (18-25 years) groups ($p < .05$). This difference, however was not dependent on run and paralleled the group difference seen in performance across background types that was described earlier in this section.

Target accuracy: 3-back memory trials. Three-back target-trial accuracy means for each age group and background are presented in Figure 21. The ability to correctly identify matches 3 trials back in a sequence was analyzed using a 4 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA. Results showed main effects of age group ($F(3, 264) = 5.83$, $p = .001$, $\eta^2 = .062$) and trial background ($F(3, 88) = 2.80$, $p < .05$, $\eta^2 = .087$). The ANOVA also revealed a gender x background interaction ($F(3, 264) = 4.29$, $p < .01$, $\eta^2 = .046$). *Post hoc* comparing performance in the four age groups found a significantly lower accuracy in the youngest (11-12 years) versus the oldest (18-25 years) age group ($p < .05$).

The main effect of background was followed up using paired-samples t-tests. Results demonstrated significantly lower accuracy on negative trials versus scrambled ($t(95) = 4.58$, $p < .001$) and neutral ($t(95) = 2.95$, $p < .01$) trials. There was also a trend for lower accuracy scores on negative trials than on positive ones ($t(95) = 1.79$, $p = .077$).

Positive trials also had significantly lower accuracy rates in comparison to scrambled trials ($t(95) = 2.00$, $p < .05$).

The gender x background interaction was followed up with repeated measures ANOVAs looking at background effects in each gender group separately. Target accuracy on the 3-back memory condition for each gender is presented in Figure 22. Both genders showed significant effects of trial background (female - $F(3, 138) = 5.98$, $p = .001$, $\eta^2 = .115$; male - $F(3, 126) = 4.38$, $p < .01$, $\eta^2 = .094$). Each background type was then compared using paired-samples t-tests for females and males separately. Females showed significantly poorer accuracy on negative versus scrambled ($t(49) = 2.78$, $p < .01$) and neutral ($t(49) = 2.30$, $p < .05$) trials and, similarly, poorer accuracy on positive versus scrambled ($t(49) = 3.50$, $p = .001$) and neutral ($t(49) = 3.20$, $p < .01$) trials. In contrast, males did not show any significant differences in accuracy between positive and neutral or scrambled trials. The male group did, however, demonstrate significantly poorer accuracy on negative trials relative to scrambled ($t(45) = 3.66$, $p = .001$) *and* positive ($t(45) = 3.16$, $p < .01$) trials, as well as a trend towards decreased performance relative to neutral trials ($t(45) = 1.93$, $p = .06$).

Despite the lack of a significant age group by background interaction, in order to investigate the *a priori* prediction that the disruption caused by emotional background types would vary with age, paired samples t-tests were used to compare accuracy on different trial background types within each age group. Patterns of significant differences vary somewhat between age groups. The 11-12 year-old group showed significantly lower accuracy on negative trials than on both scrambled ($t(23) = 2.71$, $p < .05$) and neutral ($t(23) = 2.36$, $p < .05$) trials. In the 13-14 year-old group, performance on

negative trials was significantly lower than performance on neutral trials ($t(23) = 2.16$, $p < .05$) but not different from performance on scrambled or positive trials. Accuracy on positive trials was also significantly lower than on neutral trials in this age group ($t(23) = 2.13$, $p < .05$). In the 15-16 year-old group, scrambled trials demonstrated significantly higher accuracy rates compared to negative ($t(23) = 3.35$, $p < .01$) and neutral ($t(23) = 2.49$, $p < .05$), but not positive trials. The 18-25 year-old group revealed only one significant difference in performance between background types. For this group, accuracy on negative trials was significantly lower than that on scrambled trials ($t(23) = 2.14$, $p < .05$). While the patterns of significant differences do vary between age groups, results across groups conform to the general pattern of accuracy being lowest in the emotionally distracting trials – particularly the negative ones - and highest in the scrambled trials.

Performance on the first and last scrambled-trial runs were analyzed via a 4 (age group) x 2 (gender) x 2 (run: 1 vs. 3) mixed model ANOVA. Results revealed a trend-level main effect of age group ($F(3, 88) = 2.65$, $p = .054$, $\eta^2 = .083$) and a significant age group x run interaction ($F(3, 88) = 3.05$, $p < .05$, $\eta^2 = .094$). A three-way age group x gender x run interaction also reached trend levels of significance ($F(3, 88) = 2.60$, $p = .057$, $\eta^2 = .081$). *Post hoc* comparisons of performance in each group revealed a trend for accuracy to be significantly lower in the 11-12 year-old group than in the 18-25 year-old group ($p = .052$). This pattern of results parallels that found for accuracy across trial types described earlier in this section. The interaction effects were followed up via mixed-model ANOVAs (2 (gender) x 2 (run)) performed for each age group. The 15-16 year-old group only demonstrated a significant effect of run ($F(1, 22) = 8.34$, $p < .01$, η^2

= .275), with performance on run 3 (mean accuracy = 70.79, sd = 23.1) being much stronger than in run 1 (mean accuracy = 59.08, sd = 17.0). The youngest group (11-12 years), however, showed a significant gender x run interaction ($F(1, 22) = 5.52$, $p < .05$, $\eta^2 = .201$). Follow-up paired t-tests looking at the effect of run in both genders within this age group revealed no effect of run in the 11-12 year-old female group (run 1 accuracy = 46.2%, sd = 27.4%; run 2 accuracy = 58.9%, sd = 21.0%) and a trend for decreasing accuracy between runs in the 11-12 year-old males ($t(10) = 1.99$, $p = .073$; run 1 accuracy = 62.2%, sd = 18.4%; run 2 accuracy = 47.0%, sd = 27.6%). Thus, the youngest females showed improved accuracy between the first and last round of the task, while the males of the same age performed worse on 3-back match accuracy by the end of the task, producing a gender x run interaction.

Non-target accuracy: 0-back trials. Accuracy on non-target trials (ie. not Xs) was investigated via a 4 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA. This analysis revealed a significant main effect of age group ($F(3, 88) = 8.03$, $p < .001$, $\eta^2 = .215$). No other effects were significant. *Post hoc* comparisons of accuracy on non-target trials between groups showed significantly poorer performance in the 11-12 year- old group as compared to the 13-14 year-old group ($p < .01$), the 15-16 year-old group ($p < .001$) and the 18-25 year-old group ($p = .001$).

Non-target accuracy: Potential confound. While the letter X never appeared as a target trial in the 2-back or 3-back memory conditions, we worried that participants may be primed to respond to Xs as targets given the instructions of the 0-back condition (target = X). Thus, false positive errors made on X trials during the memory conditions might indicate a lapse in rule-switching or response inhibition capacity rather than a

working memory failure. Averaging non-match trial accuracy across the two memory conditions (2- and 3-back), a 2 (letter: X vs. not X) x 2 (gender) x 4 (age group) mixed-model ANOVA revealed significantly lower accuracy on non-matching X trials relative to non-match trials featuring other letters ($F(1, 88) = 187.3$, $p < .001$, $\eta^2 = .680$). No significant interactions between letter and age group or letter and gender were found. Therefore, in order to provide the best measure of working memory performance, X trials were excluded from subsequent analyses of the non-match trials within the 2- and 3-back memory conditions.

Non-target accuracy: Two-back trials. Non target 2-back accuracy means are presented in Figure 23. Within the 2-back memory condition, accuracy on non-match trials was analyzed using a 4 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA. The analysis revealed a main effect of age group ($F(3, 88) = 3.39$, $p < .05$, $\eta^2 = .104$) and a main effect of trial background ($F(2.5, 223) = 3.34$, $p < .05$, $\eta^2 = .037$). The main effect of age group was followed up with *post hoc* comparisons, revealing a significant improvement in accuracy between the 11-12 year-old group and the 18-25 year-old group.

Non-match accuracy on each type of trial background was compared via paired-samples t-tests. These tests found significantly lower accuracy on positive compared to neutral background trials ($t(95) = 3.29$, $p = .001$), and, in turn, lower accuracy on neutral trial vis-à-vis scrambled trials ($t(95) = 2.00$, $p < .05$). No significant differences were found between negative trial accuracy and that of any other background type.

Paired-samples t-tests performed contrasting non-target accuracy on the four background types within each age group revealed effects in only the 13-14 year-old age

group. In this group, accuracy on positive trials was significantly lower than on scrambled ($t(23) = 2.06$, $p = .05$), neutral ($t(23) = 3.87$, $p = .001$) and negative ($t(23) = 2.65$, $p < .05$) trials.

Fatigue and practice effects were evaluated using a 4 (age group) x 2 (gender) x 2 (run: 1 vs. 3) mixed model ANOVA. A main effect of age group ($F(3, 88) = 2.93$, $p < .05$, $\eta^2 = .091$) was found, as well as a significant run x group interaction ($F(3, 88) = 3.12$, $p < .05$, $\eta^2 = .096$). As in the analysis including all trial backgrounds, *post hoc* comparisons of the scrambled runs revealed a significant improvement in accuracy between the 11-12 year-old group and the 18-25 year-old group ($p < .05$). The run x age group interaction was broken down via paired-samples t-tests, comparing accuracy on the two scrambled trial runs within each age group. Results revealed only one group exhibiting a trend level effect of run. The 15-16 year-old group showed improved performance between the first and last runs of the 2-back task ($t(23) = 2.06$, $p = .05$; run 1 mean accuracy = 89.6%, sd = 12.3; run 3 mean accuracy = 95.0%, sd = 8.3%). No other age groups demonstrated significant changes in non-match trial accuracy between the two scrambled runs of the 2-back task.

Non-target accuracy: 3-back trials. Mean 3-back non-target accuracy for each age group and background type is presented in Figure 24. Accuracy on non-match trials in the 3-back memory condition was analyzed using a 4 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA. This analysis revealed main effects of age group ($F(3, 88) = 6.58$, $p < .001$, $\eta^2 = .183$) and of trial background ($F(3, 88) = 6.58$, $p < .001$, $\eta^2 = .183$). *Post hoc* comparisons were used to follow up the main effect of age. Results showed significantly lower accuracy in the 11-12 year-old age group compared to the 15-

16 year-old age group ($p < .05$) and the 18-25 year-old age group ($p < .001$). Accuracy on non-match trials was further explored via paired-samples t-tests, following up on the main effect of background by comparing performance on each background type. Results showed significantly lower accuracy in negative trials relative to scrambled ($t(95) = 5.64$, $p < .001$) and neutral ($t(95) = 3.49$, $p = .001$) trials. Likewise, accuracy on positive trials was also significantly worse than on both scrambled ($t(95) = 5.14$, $p < .001$) and neutral ($t(95) = 2.74$, $p < .01$) trials. Finally, neutral trial accuracy was also significantly lower than accuracy on scrambled trials ($t(95) = 2.25$, $p < .05$).

In accord with the prediction that the influence of different background types may vary with age group, paired samples t-tests were used to compare non-match trial accuracy on the four background categories within each age group. In the 11-12 year-old group, accuracy on negative trials was found to be significantly lower compared to both scrambled ($t(23) = 5.22$, $p < .001$) and neutral ($t(23) = 3.49$, $p < .005$) trials. In this same group, accuracy on positive trials was also found to be significantly lower than on scrambled background trials ($t(23) = 3.24$, $p < .01$). In the 13-14 year-old group, scrambled trials were again shown to have higher accuracy scores relative to both negative ($t(23) = 2.79$, $p = .01$) and positive ($t(23) = 3.26$, $p < .01$) trials. However, unlike the younger group, this group did not show a significant difference between negative and neutral background trials. The 15-16 year-old group showed no significant effects of trial background. The 18-25 year-old group, like the youngest two groups, had significantly higher accuracy scores on scrambled versus negative ($t(23) = 2.13$, $p < .05$) and positive ($t(23) = 3.60$, $p < .01$) trials. In contrast to the other groups, however, the oldest age group also showed a significant difference between positive and neutral

background trials ($t(23) = 2.25$, $p < .05$), with lower accuracy on the positive trials compared to the neutral ones.

A 4 (age group) x 2 (gender) x 2 (run: 1 vs. 3) mixed-model ANOVA was used to assess practice and fatigue effects and their relation to age and gender. The analysis revealed a main effect of run ($F(1, 88) = 6.77$, $p < .05$, $\eta^2 = .071$) with improved accuracy scores in run three (mean accuracy = 90.3, sd = 11.4) relative to run one (mean accuracy = 86.8, sd = 11.7). The ANOVA did not show any significant main or interaction effects of age or gender.

Target reaction time. Reaction time on correctly identified target trials was averaged across memory conditions (0-back, 2-back, 3-back). The influence of age group, gender and trial background was then examined via a 4 (age group) x 2 (gender) x 4 (background) mixed-model ANOVA. Results revealed a main effect of background ($F(2.7, 237.1) = 6.95$, $p < .001$, $\eta^2 = .073$) but no significant main effects of age group or gender, as well as no significant interaction effects. Paired-samples t-tests were used to follow up on the main effect of background. Results revealed significantly slower reaction times on positive trials relative to negative ($t(95) = 2.46$, $p < .05$), neutral ($t(95) = 5.24$, $p < .001$), and scrambled ($t(95) = 3.36$, $p = .001$) trials. No other significant differences were found.

In order to evaluate the effect of memory load on response times, data were averaged across background types and entered into a 4 (age group) x 2 (gender) x 3 (memory load) ANOVA. This analysis showed a significant effect of memory load ($F(1.6, 140.6) = 93.86$, $p < .001$, $\eta^2 = .516$) but no interactions of memory load with age group or with gender. Differences in reaction time between the memory conditions were

all highly significant, with response times on the 0-back task being significantly faster than on both the 2-back ($t(95) = 10.39$, $p < .001$) and 3-back task ($t(95) = 11.10$, $p < .001$) and responses on the 2-back task being significantly faster than those on the 3-back task ($t(95) = 5.42$, $p < .001$). Thus reaction times on target trials was clearly slowed by increasing memory load and appeared to be influenced by the presence of positive background images. However, this measure of performance showed no measurable relationship to age or gender.

Relationship Between Tasks

To explore the relationship between performance on the go-nogo and n-back tasks, accuracy on nogo trials and accuracy on 3-back match trials were selected as the most representative measures of inhibitory control and working memory, respectively. Pearson correlations were then performed, comparing performance in equivalent background categories (negative, positive, neutral, scrambled) across tasks. Significant correlations were found for each background type (negative: $r = .239$, $n = 96$, $p < .05$; positive: $r = .214$, $n = 96$, $p < .05$; neutral: $r = .273$, $n = 96$, $p < .01$; scrambled: $r = .414$, $n = 96$, $p < .001$). However, when age in months was entered as a covariate, the correlation remained significant only in the neutral ($r = .271$, $n = 96$, $p < .01$) and scrambled ($r = .328$, $n = 96$, $p < .01$) background conditions.

Subjective Ratings of IAPS Images

Averaged ratings of valence and arousal for each category of IAPS images (negative, positive, neutral) were computed for each of the age groups. Means are

presented in Table 5. Using the average rating for each image, a multivariate ANOVA was run with age group as the predictive variable. Results showed no significant difference between age groups for any of the image rating measures. However, a trend effect of age group was observed on the negative valence measure ($F(3, 476) = 2.60$, $p = .051$). *Post hoc* contrasts showed a trend for the 13-14 year-old group to rate the negative slides higher (thus less negative) relative to the adult group ($p = .058$). The ANOVA also revealed a trend-level effect of age group on the arousal rating on the positive slides ($F(3, 476) = 2.42$, $p = .066$). In this case *post hoc* contrasts revealed no significant differences between groups, though the 13-14 and 18-25 year-old groups again showed the greatest disparity between means, with the adolescent group rating the positive slides as less arousing compared to the ratings of the same slides by the adult group.

Arousal

	Negative	Positive	Neutral
11-12	5.12	4.75	2.68
13-14	4.86	4.24	2.62
15-16	5.09	4.69	2.74
18-25	5.15	4.78	2.79
Norms	5.32	4.94	3.35

Valence

	Negative	Positive	Neutral
11-12	3.03	6.76	5.07
13-14	3.35	6.87	5.21
15-16	3.21	6.78	5.06
18-25	2.91	7.07	5.37
Norms	3.12	7.32	5.25

Table 5. Subjective ratings of arousal and valence for each age group. Valence ranges from 1 (very negative) to 9 (very positive). Arousal ranges from 1 (not arousing) to 9 (highly arousing).

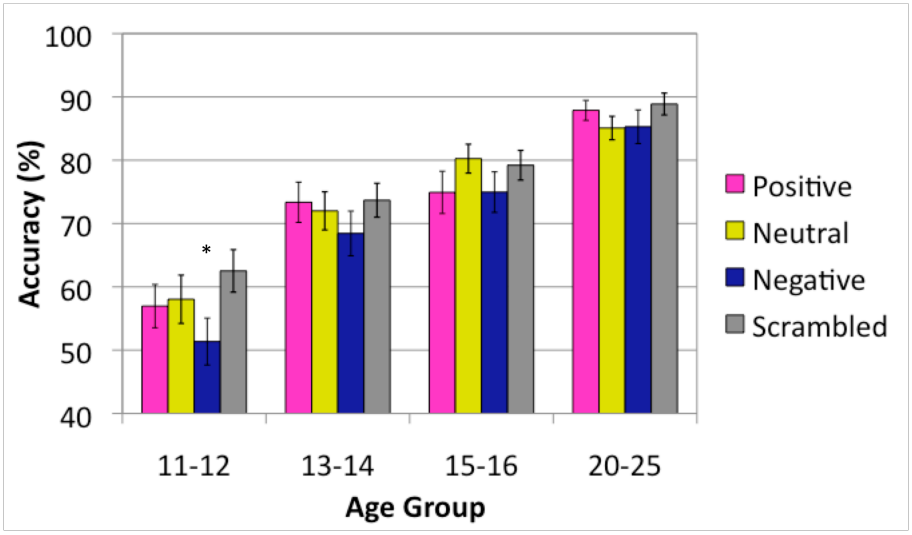

Figure 15. Accuracy on nogo trials for all age groups and background types.

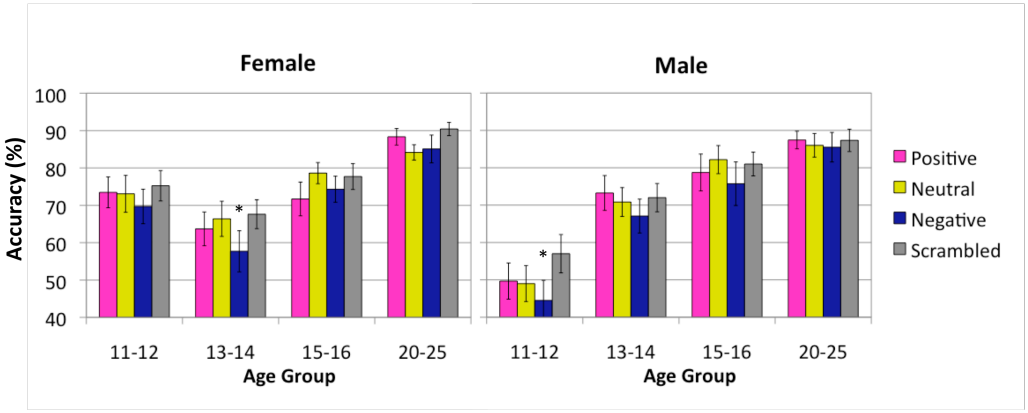

Figure 16. Accuracy on nogo trials for males versus females in all age groups and background types.

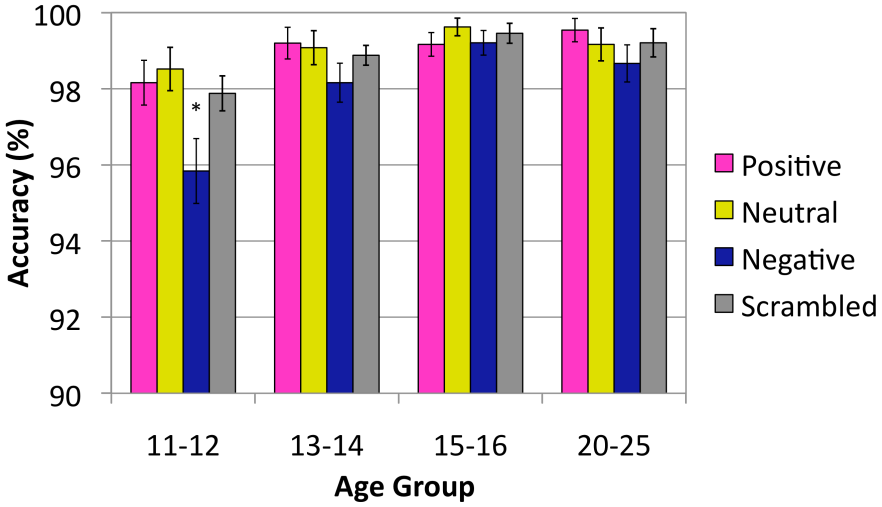

Figure 17. Accuracy on go trials for all age groups and background types.

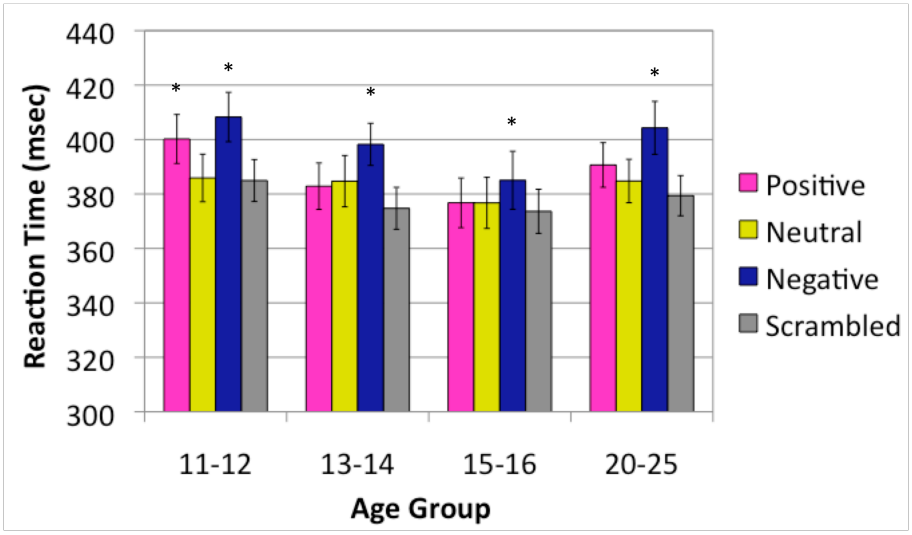

Figure 18. Reaction times on correct go trials for all age groups and background types.

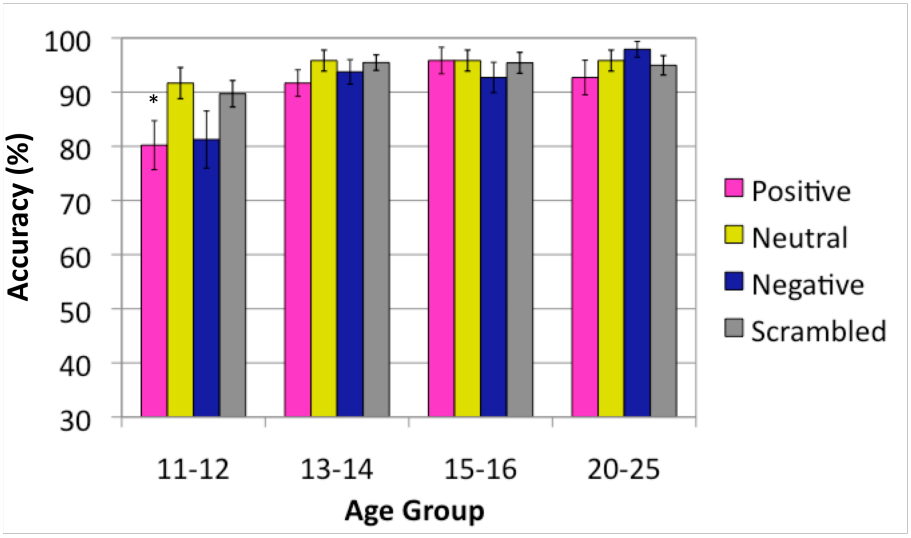

Figure 19. Accuracy on 0-back target trials for all age groups and background types.

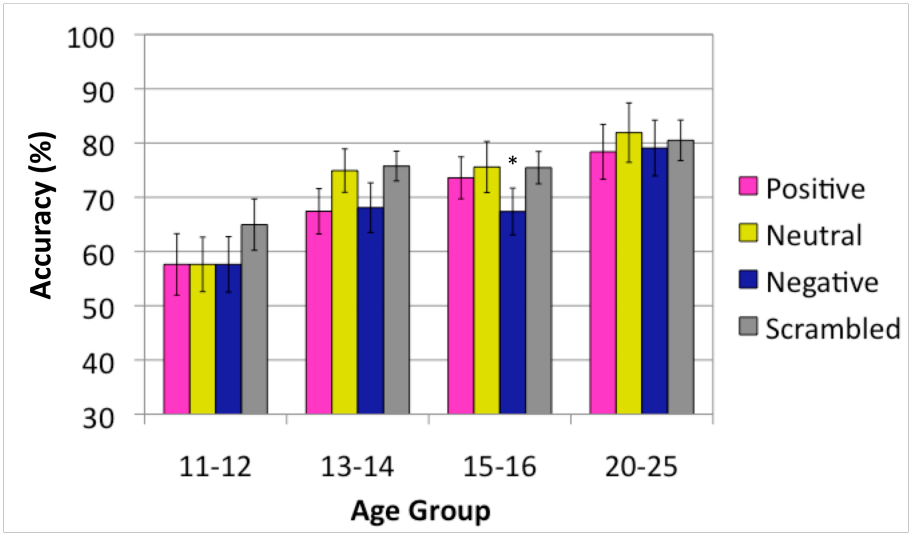

Figure 20. Accuracy on 2-back target trials for all age groups and background types.

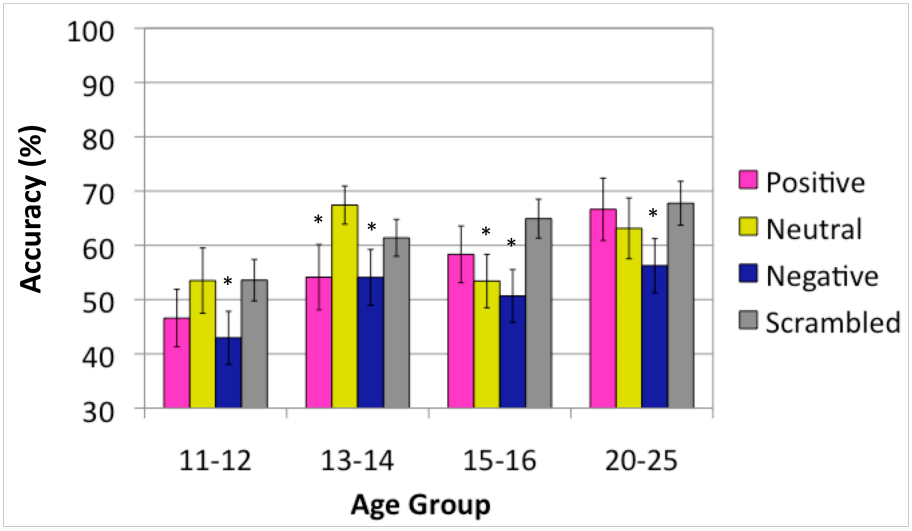

Figure 21. Accuracy on 3-back target trials for all age groups and background types.

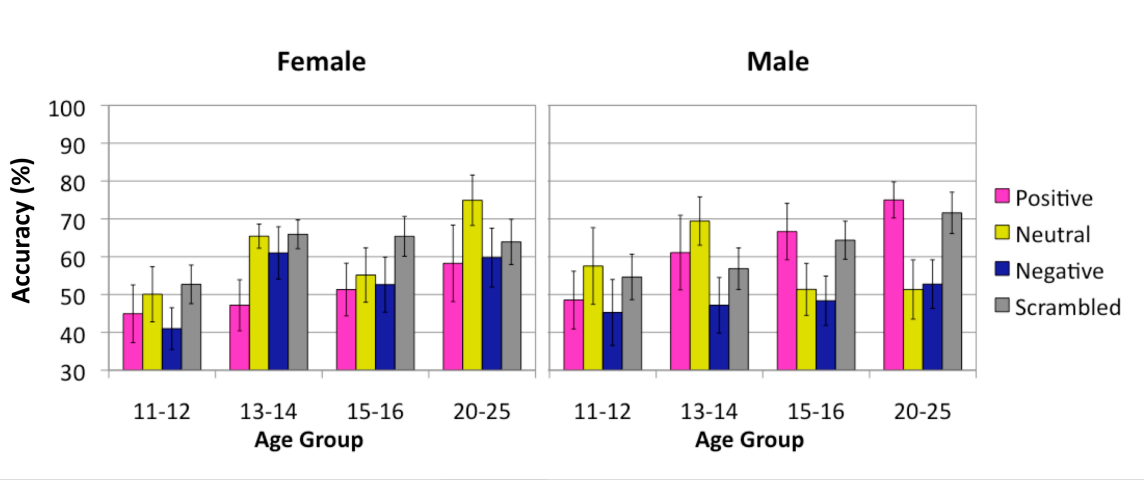

Figure 22. Accuracy on 3-back target trials in males versus females for all age groups and background types.

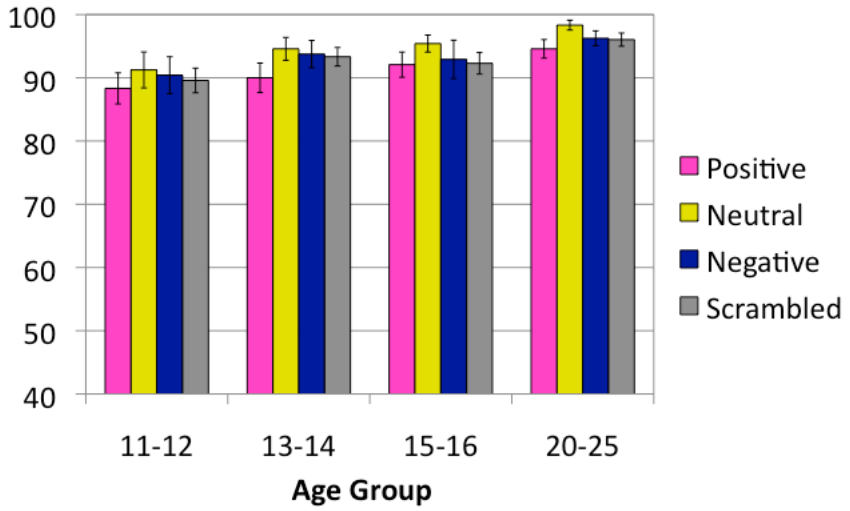

Figure 23. Accuracy on 2-back non-target trials for all age groups and background types.

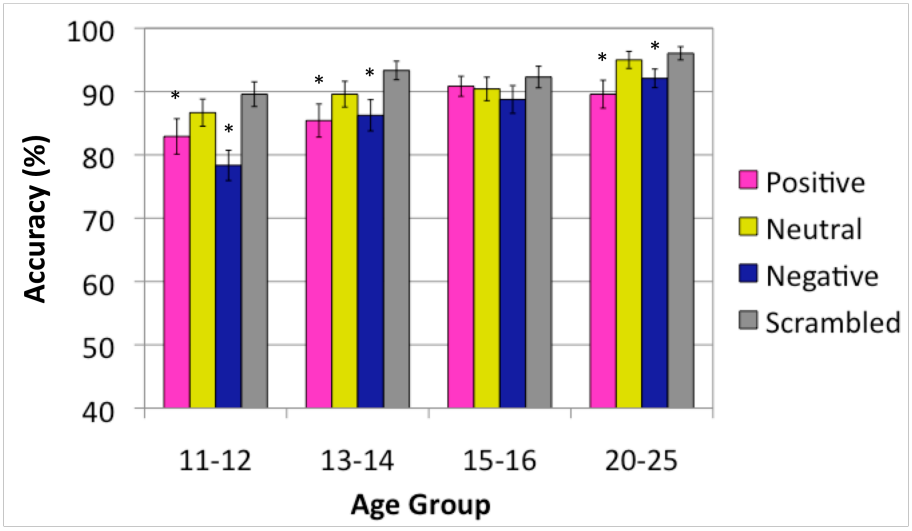

Figure 24. Accuracy on 3-back non-target trials for all age groups and background types.

Discussion

Go-nogo Task

The current study did replicate several effects found in the original behavioral study using this go-nogo task. As in the previous two studies, nogo trial accuracy improved between 11 and 18 years of age, indicating continued increases in inhibitory control capacity throughout adolescence and possibly beyond. Differences in accuracy on the four different types of background also revealed a similar developmental pattern to that seen in the original behavioral study. That is, nogo trial accuracy on negative background trials was significantly worse than on all other background types while accuracy on scrambled trials was better than on negative, positive and neutral backgrounds – albeit only at trend level in the case of neutral trials. However, unlike the study described in chapter one, this go-nogo task revealed neither an age group by background interaction nor an age group by gender by background interaction, suggesting that the gender effects evident in chapter one may have been an artifact due to a small sample size. More power would be needed to adequately address questions regarding gender differences.

Follow-up analyses revealed a significant effect of age group only in the youngest group (11-12 years). It is possible that this shorter version of the go-nogo task was simply not as sensitive due to the reduction in both attentional demands and/or the range of content presented in the background for any given participant. Context effects may also have influenced performance, including the need to keep still for the sake of electrophysiological recording or the fact that half of the participants completed a

different cognitive task using very similar stimuli immediately before completing the go-nogo.

While no background by gender interaction was found in the 15-16 year-old group, the 11-12 year-old group did show a main effect of gender, with females outperforming males, not seen in the previous behavioral sample. The reason for this difference is not clear, but could reflect either differences in effort or differences in ability to do the task while also keeping very still.

Some of the previously observed effects of background were seen within age groups. For example the 11-12 year-old group showed effects of distraction from both negative and positive images on nogo accuracy. The 13-14 year-old group revealed only trend-level effects. However, lower accuracy was again seen in negative versus other trial types, thus following roughly the same pattern as that seen in the equivalent age group in chapter one. Likewise, the 15-16 year-old group showed reduced nogo trial accuracy on negative compared to neutral slides. The 18 to 25 year-old group again showed no differences in nogo accuracy as a function of emotional content but did have significantly lower accuracy on neutral versus scrambled trials. Thus, there does appear to be a developmental progression from disruption by both positive and negative images to disruption by negative image content only, followed by a reduction in the effect of any type of image content, regardless of valence.

Much as in the nogo trial accuracy data, the go trial accuracy results showed age related improvements and a main effect of background, with accuracy on negative trials being significantly lower than on all other trial types. The lower accuracy on negative relative to other trial types seen in the youngest group fits well with the findings from the

previous study and other performance metrics. These differences of performance on non-inhibitory trials again raise the question of whether age-related improvements are exclusively in response inhibition or also reflect maturation of other attention-related or regulatory capacities.

Reaction time on go trials, when analyzed across groups, showed all of the previously observed effects of background. That is, negative trials showed significantly longer response times relative to all other trial types while positive trials show slower responses than neutral and scrambled trials, and finally neutral trial response times were significantly longer than those for scrambled trials. Thus as the emotional salience of the background was increased, so was the time it took to respond to the letter stimulus placed at its center. As in chapter one, a pattern of response slowing for negative backgrounds across age groups was also seen. The two younger age groups also showed effects of positive backgrounds. These distracting effects of positive backgrounds then appeared to diminish with age, suggesting that the positive images either were less generally salient, compared to the negative images, and therefore were more readily ignored at a younger age, or that the attention-capturing qualities of these images was different for different age groups. This effect, however, was not evident in the original study and must be interpreted with some caution.

N-back Task

Results of the n-back task varied considerably depending on the memory condition and performance measure of interest. The majority of measures showed some evidence of improvement across the age range studied and some disruptive effects of the

presence of emotional backgrounds. However, the relative salience of positive versus negative backgrounds as well as the relationship between age and background varied from measure to measure and did not show the same consistent distracting effect of negative backgrounds as was seen in the go-nogo. Detecting the target letter (X) in the 0-back condition primarily required sustained attention and some motor control as well as suppression of interference by the emotional distractors. Accuracy on this task was significantly worse in the youngest age group compared to all three other groups, suggesting that the youngest participants had more difficulty staying on task and switching between the two response options as needed. No differences were seen between the older groups, suggesting more adult-like performance on this aspect of the task from age 13 and up. Furthermore, when accuracy was compared within groups, the general finding of lower accuracy on both positive and negative trials relative to less emotional stimuli was significant only in the 11-12 year-old group. This suggests that the youngest participants not only struggled more with the basic attentional component of the task, but also has difficulty suppressing or screening out interference from the emotional distractors presented in the background. In all age groups, accuracy on target detection declined over the course of the task, likely due to increasing interference from the alternate rule sets for the two memory conditions as well as cognitive fatigue.

Target detection in the 2-back memory condition showed improvements between the 11-12 year-old group and the 15-16 and the 18-25 year-old groups. Thus, unlike in the 0-back condition, performance on the 2-back does not improve significantly between the two younger groups, possibly because of a slower rate of improvement with age on a more difficult task. As on the 0-back, target accuracy on the 2-back was lower for

emotional background trials (positive and negative) relative to non-emotional trials. When results were broken down by age group, in the 2-back task, the 13-14 and 15-16 year-old age groups showed effects of background, while the 11-12 year-old group did not. Significant effects in the youngest group, however, may have been obscured by higher variability in performance. The appearance of background effects in the older age groups suggests that the introduction of a memory load may have rendered the older adolescents more readily disrupted by background information than when they were completing the simpler 0-back task.

Accuracy on 3-back target trials, in fact, continues two of the patterns established by the 0- and 2-back tasks. First, improvement between age groups is only seen between the youngest and oldest age groups, suggesting a still slower rate of improvement on the most difficult of the three n-back tasks. Also, target accuracy measures on the 3-back revealed disruptive effects of negative backgrounds in all four age groups. This again suggests that as the memory load increased older participants became more readily affected by background content. This pattern could be explained via a limited-resource model of executive control in which total available resources correlates positively with age. That is, if efforts to maintain new letters in memory while deliberately discarding others taps into the same pool of cognitive resources as efforts to screen out extraneous emotional inputs, the ability to ignore the images will decrease as memory demands go up. Then, if the general resources available increase with age across adolescence, younger teens will show effects of emotional distraction on easier tasks while older adolescents with only show such effects as other executive demands increase. This pattern was not evident in the go-nogo task. However, this difference may either be due

to the go-nogo task being insufficiently difficult for older adolescents to show effects of emotional distraction or be due to the cognitive requirements of the two tasks being sufficiently different that task demands interact with the distracting emotional images in inherently different ways. A parametric manipulation of go-nogo difficulty might resolve this question, although increasing task difficulty typically would involve shortening trials, which would have the side effect of shortening image presentation and thus potentially emotional impact of the images.

Correlations between nogo trial accuracy and 3-back target accuracy suggest that performance on these two measures is at least somewhat related. When age is entered as a covariate, however, correlations between tasks do not remain significant on the positive or negative background conditions, suggesting that the introduction of images may influence working memory and response inhibition in different ways. For example, while negative images were consistently the most disruptive image type in all measures of nogo accuracy, several n-back measures showed increased interference by positive images, sometimes even superseding that of negative images (e.g. 2-back non-target accuracy and overall n-back reaction times).

Subjective ratings of the IAPS slides did not suggest any major discrepancies in groups ratings of the three classes of slides. The small effects that were evident conform with theories suggesting increased novelty seeking in adolescent males is perpetuated by diminished fear responding or the reduction of arousal responses to familiar rewards (Spear, 2000a; Spear, 2000b; Steinberg, 2005; Steinberg et al., 2006). However, there is no suggestion in task performance that males in this age group (13-14 years) are less readily disrupted by emotional images compared to other age groups.

In summary, developmental changes in performance on the emotional-distraction executive function tasks used in this study may be influenced more heavily by cognitive capacity than by emotional reactivity during adolescence. This suggestion is supported by the presence of emotional disruption effects in the older age groups when cognitive demands were increased, as well as by the slowed reaction time to emotionally salient slides seen in all age groups, across studies and cognitive tasks. This conclusion is also supported by the absence of significant age differences in subjective ratings of the slides and by the lack of any relationship between group ratings and task performance.

Through testing the same participants on both a working memory task and an inhibitory control task while using IAPS images as emotional distractors, this study extends our understanding of the relationship between different forms of executive function and the ability to cope with emotional distraction as it develops across adolescence. The following chapter introduces new questions regarding the roles of early experience and genetics on the interplay of emotion and executive function in adolescence.

Chapter 4: Effects of Early Stress and BDNF Genotype on Response Inhibition During Emotional Distraction in Adolescence

Self-regulation in emotional contexts can be particularly challenging for adolescents who have experienced early stress. Individuals who spent their early years in institutions that did not provide adequate social or cognitive stimulation have been found to struggle with executive function and emotional regulation later in life (e.g. Pollak et al., 2010; Sigal, Perry, Rossignol, & Ouimet, 2003). The transition into adolescence can be accompanied by the emergence of new behavioral sequelae of early stress, making early adolescence an age of particular interest when exploring these effects. Genes may interact with early environmental factors to either support or undermine the successful development of self-regulation and inhibitory control during early adolescence. Previous work has suggested that val66met polymorphism of the brain-derived neurotrophic factor (BDNF) gene may moderate the effects of early stress on later cognitive functioning and stress responses (e.g. Hayden et al., 2010). BDNF is of particular interest as it plays a key role in the development of brain structures such as the hippocampus and amygdala (Hariri et al., 2003; Frodl et al., 2007). The following study explores the influence of duration of institutionalization and BDNF genotype on the ability to inhibit prepotent responding in the context of emotional distraction.

This study examines the ability to exert inhibitory control in spite of emotional distraction in a sample of internationally adopted children who spent the bulk of their pre-adoptive lives in institutional care. Performance on executive tasks in this population is of particular interest given that this form of early stress has been shown to affect

development of the prefrontal cortex (Carrion et al., 2001; Chugani et al., 2001; De Bellis, 2005) and because adolescents in this population frequently exhibit deficits in cognitive skills that rely on prefrontal functioning (Beckett et al., 2006; Gunnar & Van Dulmen, 2007). Furthermore, chronic stress has been linked to changes in amygdala structure and functioning (see McEwen, 2005 for review) as well as changes in stress responses and increased fear/anxiety behavior - presumably mediated in part by the amygdala (see Davidson, Pizzagalli, Nitschke, & Putnam, 2002 for review). In this study, the emotional distraction go-nogo task is used to evaluate how early institutional care relates to adolescents' abilities to successfully inhibit prepotent motor responses while screening out irrelevant emotional information that can be either threatening or appetitive. We hypothesized a negative relationship between the time spent in institution and performance on this task and a possible interaction between age at adoption and BDNF genotype, wherein children who were adopted late and possess a Met allele may be particularly at risk for poor performance on executive function tasks during emotional distraction.

Method

Participants

Participants in this study were recruited from the Minnesota Adoption Project participant registry as part of a larger study looking at the contributions of BDNF genotype and early institutional care to behavioral and cognitive outcomes in early adolescence. Ninety-two participants (32 male) between the ages of 12.5 and 14.5 years (mean age = 13.23 years) were included in the current sample. Phase one of this study

included the completion of surveys and submission of a saliva sample. Saliva samples were used to genotype participants for the val66met polymorphism of the BDNF gene. A subset of participants were then invited to participate in a second phase of the project based on their age, gender, genotype, and duration of time spent in an orphanage or other institutional care. That is, participants were recruited in a stratified fashion in order to provide a balanced sample of the more common (val/val) polymorphism, and the more rare (val/met or met/met) polymorphisms. Recruitment also prioritized a broad range of time in institution, a variety of countries of origin and a mixture of the two genders. Participants all had been adopted prior to 72 months of age and had spent between four to sixty months in orphanage care. All participants spent at least 50% of their pre-adoption life in an institutional setting. The mean proportion of pre-adoption time spent in an institution for this sample was 92%. It was not possible to match gender as a strong majority of internationally adopted children are female. Therefore, as many male participants as possible were recruited. However, due to the discrepancy in sample size for the two genders, effects of gender will not be discussed.

Participants were excluded for chromosomal anomalies, Autism or Autism Spectrum disorders, Tourette Syndrome, Fetal Alcohol Syndrome or seizure disorders. See Table 6 for a breakdown of region of origin, age at adoption, genotype and gender. Given the sample size, it was not possible to control for country of origin. For the purpose of analysis, the sample was subdivided into an early-adopted group (adopted prior to 12 months) and a late-adopted group (adopted at 12 months or later).

	Val/Val		Val/Met		Met/Met		
	Early	Late	Early	Late	Early	Late	**Total**
Southeast Asia	2(0)	7(0)	11(3)	6(0)	4(0)	2(0)	**32(3)**
South Asia	5(0)	1(0)	5(2)	2(1)	0	0	**13(3)**
Europe	8(4)	16(9)	2(1)	11(6)	0	0	**37(20)**
South America	4(3)	3(1)	1(1)	1(0)	0	0	**9(5)**

Table 6. Region of origin, genotype and gender distribution of participants. Values are listed as: total participants(male).

Behavioral Task

The task used in the current experiment was the same as the task employed in chapter one (see Figures 1 and 2). Stimuli were presented on a 21" monitor. Background images, however, covered a 12"x7.5" area of the screen. Letters were again presented in a small box at the center of the image. Reaction time data on correct go trials as well as response accuracy data for both nogo and go trials were recorded for each participant during all three runs.

Behavioral Data Analysis

Reaction times on go trials, accuracy on go trials and accuracy on nogo trials for each background type (positive, negative, neutral and scrambled) served as dependent variables. Duration in institutional care (early vs. late adopted) and genotype (no met allele vs. one or more met alleles) were used as the main predictors of differences in performance. Nogo trial accuracy, go trial accuracy and go trial reaction time were each analyzed via mixed-model ANOVAs including age at adoption (early = < 12 months

versus late = > 12 months) and genotype (NoMet = val/val versus Met = val/met or met/met) as between-subject factors and trial background type (negative, positive, neutral, scrambled) as a within subject factor. Greenhouse-Geisser corrections were used in cases where Mauchly's test indicted a violation of the assumption of sphericity. Significant effects of background were followed up using paired-samples t-tests (two-tailed).

IQ Assessment

The Weschler Abbreviated Scale of Intelligence was administered by a trained clinical psychologist shortly after participants completed the go-nogo task. Full scale IQ scores were computed based on participants performance on all four subtests: Vocabulary, Similarities, Block Design, and Matrix Reasoning. Eight participants were excluded from analyses involving IQ scores due to not having completed the WASI. Thus, IQ-related analyses report results from a sample of 83 adolescents.

Genetic Methods

Saliva samples were collected using the Oragene system (DNA Genotek). This system stabilizes genomic DNA in a lysis solution when the collection cup is closed. Samples were thus stable at room temperature (for up to a year). Samples were coded with a unique numeric identifier and mailed to colleagues at Weill Medical College of Cornell University for genotyping. A full description of the genotyping methods may be found in Soliman et al. (2010).

Results

Go-Nogo Task Performance

Nogo trial accuracy. In order to explore the effects of age at adoption and BDNF genotype on inhibitory control during emotional distraction, a 2 (age at adoption) x 2 (genotype) x 4 (background) mixed-model ANOVA was run. This analysis revealed a main effect of background ($F(2.7, 228) = 36.19$, $p < .001$, $\eta^2 = .304$). The ANOVA also showed two significant interaction effects: age at adoption x genotype ($F(1, 83) = 5.98$, $p < .05$, $\eta^2 = .067$) and a three-way background x age at adoption x genotype interaction ($F(2.7, 228) = 3.06$, $p < .05$, $\eta^2 = .036$). Mean accuracy on nogo trials for each genotype group and age at adoption (early vs. late) is presented in Figure 25.

The main effect of background was followed up using paired-samples t-tests to contrast nogo trial accuracy for each of the four background types. Results showed significant differences between all background types. As in experiments 1 through 3, accuracy on negative nogo trials was significantly worse when compared to scrambled ($t(90) = 9.84$, $p < .001$), neutral ($t(90) = 6.20$, $p < .001$), and positive ($t(90) = 3.5$, $p = .001$) trials. Positive trials, furthermore, showed lower nogo accuracy relative to both neutral ($t(90) = 3.74$, $p < .001$) and scrambled ($t(90) = 6.68$, $p < .001$) trials. Finally, neutral trials presented lower accuracy scores relative to scrambled trials ($t(90) = 3.94$, $p < .001$). Thus, this sample showed the full set of predicted effects in nogo trial accuracy previously seen only in reaction time data in prior samples.

The interaction effect between background, age at adoption and genotype was followed up using two separate 2 (age at adoption: early vs. late) x 4 (background:

negative, positive, neutral, scrambled) mixed model ANOVAs for each of the two genotype groups: NoMet and Met. A main effect of background type was found in both the NoMet group ($F(3, 132) = 18.50$, $p < .001$, $\eta^2 = .296$) and the Met group ($F(2.5, 108) = 23.65$, $p < .001$, $\eta^2 = .355$). However, only the Met group revealed a significant effect of age at adoption ($F(1, 43) = 7.81$, $p < .01$, $\eta^2 = .154$), with late adopted participants performing significantly worse on nogo accuracy compared to early adopted children.

The effect of background found in both the NoMet and Met groups was followed up via paired-samples t-tests comparing performance between background types within each genotype group. In the NoMet group, only one significant difference in accuracy due to background types was found. Specifically, accuracy on negative trials was found to be lower than on neutral trials ($t(41) = 2.28$, $p < .05$). In the Met group, negative trials showed lower accuracy that all three other background types: scrambled ($t(40) = 1.99$, $p = .05$), neutral ($t(40) = 2.28$, $p = .01$), and positive ($t(40) = 2.86$, $p < .01$).

In order to determine which background trial types were influenced by age at adoption and genotype, two multivariate ANOVAs were performed, one for the early adopted group and one for the late adopted group, for nogo accuracy on each background type, with genotype as the fixed factor. Only negative trials in the late adopted group showed a significant effect of genotype ($F(1, 47) = 5.68$, $p <.05$, $\eta^2 = .108$).

A 2 (age at adoption: early vs. late) x 2 (genotype: no met vs. met) x 2 (run: 1 vs 3) mixed-model ANOVA was run using data from the scrambled-only blocks at the beginning and end of the task in order to check for practice or fatigue effects and their relation to the variables of interest. The ANOVA revealed only one effect – a main effect of run ($F(1, 83) = 3.98$, $p < .05$, $\eta^2 = .046$) resulting from lower overall accuracy on the

final run (mean accuracy = 64.8%) when compared to the first run (mean accuracy = 67.1%). While there was no effect of group and no group x run interaction, it is worth noting that no such decline in performance over time was not observed in the previously described 13-14 year-old non-adopted samples (see chapter 1). However, due to differences in study design, these samples are not directly comparable. In particular, participants in this study completed the go-nogo task immediately after performing two other challenging cognitive tasks, while participants in the normative sample were asked only to complete questionnaires and the go-nogo task during their time in the lab. Thus, boredom and fatigue in the internationally adopted group is likely to have been greater than in the previous study.

Go trial accuracy. Accuracy on go trials was analyzed via a 2 (age at adoption: early vs. late) x 2 (genotype: no met vs. met) x 4 (background) mixed-model ANOVA. The analysis revealed a main effect of background ($F(2.1, 171) = 8.15$, $p < .001$, $\eta^2 = .089$) and a three-way background x age at adoption x genotype interaction effect ($F(2.1, 171) = 4.03$, $p < .05$, $\eta^2 = .046$). Paired samples t-tests, were used to contrast go trial accuracy on each of the background types. As in other samples, these analyses revealed significantly lower accuracy on negative compared to scrambled ($t(90) = 2.32$, $p < .05$), neutral ($t(90) = 3.74$, $p < .001$), and positive ($t(90) = 3.21$, $p < .01$) trials. No other comparisons between background types revealed significant effects.

The three-way interaction effect was followed up with separate 2 (age at adoption: early vs. late) x 4 (background: negative, positive, neutral, scrambled) mixed model ANOVAs for each genotype group (NoMet and Met). These results showed a significant main effect of background in the Met group ($F(2.2, 88) = 5.76$, $p < .01$, $\eta^2 = .123$) but

only a trend effect of background in the NoMet group ($F(1.9, 79) = 2.86$, $p = .066$, $\eta^2 = .064$). The Met group also demonstrated a significant background by age at adoption interaction ($F(2.2, 88) = 3.31$, $p < .05$, $\eta^2 = .075$). Follow-up comparisons of performance on different types of background trials, using paired-samples t-tests revealed that only the late adopted Met allele group showed significant differences in go trial accuracy between background types. Specifically, in this group, accuracy on negative trials was significantly worse relative to neutral ($t(21) = 2.70$, $p < .05$) and positive ($t(21) = 2.77$, $p < .05$) trials. A similar effect was also present at trend level between negative and scrambled trials ($t(21) = 2.02$, $p = .056$). Thus, the late adopted group in possession of at least one met allele was the only group that showed influence of distracting negative information on go trial performance.

A 2 (age at adoption) x 2 (genotype) x 2 (run: 1 vs. 3) mixed model ANOVA revealed a main effect of run ($F(1, 83) = 5.76$, $p < .05$, $\eta^2 = .065$), but no effects of age at adoption or genotype and no interaction effects. Thus the overall decrease in go trial accuracy between the first and last scrambled runs (run 1 mean = 97.7%; run 2 mean = 96.8%) did not differ based on age at adoption or genotype.

Go trial reaction time. Go trial reaction times for early versus late adopted participants are presented in Figure 26. A 2 (age at adoption: early vs. late) x 2 (genotype) x 4 (background) mixed-model ANOVA was used to analyze reaction times on correct go trials. The analysis revealed a main effect of background ($F(2.6, 214) = 80.88$, $p < .001$, $\eta^2 = .494$). There were no significant main effects of age at adoption or genotype and no significant interaction effects.

Paired-samples t-tests were used to perform *post hoc* contrasts between the four background types. Results showed significantly longer reaction times on negative background trials than on scrambled ($t(90) = 12.96$, $p < .001$), neutral ($t(90) = 12.28$, $p < .001$), and positive ($t(90) = 9.81$, $p < .001$) trials. Scrambled trials were also found to have shorter response times relative to both positive ($t(90) = 6.70$, $p < .001$) and neutral ($t(90) = 5.16$, $p < .001$) trials. In other words, responses were slowest on negative trials and fastest on scrambled ones, while neutral and positive responses fell somewhere in between.

Practice and fatigue effects were examined via a 2 (age at adoption) x 2 (genotype) x 2 (gender) x 2 (run: 1 vs. 3) mixed model ANOVA. The analysis revealed a main effect of run ($F(1, 81) = 4.65$, $p < .05$, $\eta^2 = .054$) due to response times being faster in the final scrambled block compared to the first (run 1 mean = 378.17ms; run 3 mean = 364.33ms). The ANOVA also revealed two significant interaction effects: a run x age at adoption interaction ($F(1, 81) = 5.31$, $p < .05$, $\eta^2 = .062$) and a run x genotype interaction ($F(2, 81) = 3.29$, $p < .05$, $\eta^2 = .075$). Follow up *post hoc* paired-samples t-tests found significant effects of run in both the early adopted group ($t(38) = 4.67$, $p < .001$) and the late adopted group ($t(43) = 2.07$, $p < .05$). T-tests also revealed a significant effect of run in the NoMet group ($t(41) = 3.94$, $p < .001$) and in the Met group ($t(40) = 2.46$, $p < .05$). In all cases reaction times were longer in the first run and faster in the last run of the task.

IQ Data

Overall mean IQ in this sample was 100.55 (sd = 15.23). IQ differences due to age at adoption and BDNF genotype were analyzed via a univariate ANOVA. Results

revealed a significant effect of age at adoption ($F(1, 79) = 4.25$, $p < .05$, $\eta^2 = .051$) and a significant effect of genotype ($F(1, 79) = 7.98$, $p < .01$, $\eta^2 = .092$). Mean IQ was higher in the early adopted group (mean IQ = 104.41, sd = 15.36) versus the late adopted group (mean IQ = 97.14, sd = 14.43). Mean IQ was also higher in the Met group (mean IQ = 105.34, sd = 15.29) compared to the NoMet group (mean IQ = 95.88, sd = 13.80). No significant interaction was found between age at adoption and genotype. Given these group differences, go-nogo task results were reanalyzed with IQ as a covariate.

Go-nogo Performance with IQ Covaried

Nogo trial accuracy. A 2 (age at adoption) x 2 (genotype) x 4 (background) mixed-model ANOVA with IQ entered as a covariate revealed no main effects. Results did show, however, an age at adoption x genotype interaction ($F(1, 78) = 6.63$, $p < .05$, $\eta^2 = .078$) and a trend-level age at adoption x genotype x background interaction ($F(3, 234) = 2.46$, $p = .063$, $\eta^2 = .031$). Follow-up ANOVAs for each genotype group revealed a significant effect of age at adoption in the Met group only with early adopted participants performing better than late adopted ones (early adopted mean accuracy = 68.6%, sd = 15.7%, late adopted mean accuracy = 53.4%, sd = 17.2%). Neither group showed a significant effect of background.

Go trial accuracy. A 2 (age at adoption) x 2 (genotype) x 4 (background) mixed-model ANOVA with IQ entered as a covariate found no main effects but did reveal a age of adoption x genotype x background interaction ($F(2.05, 159.9) = 3.04$, $p = .05$, $\eta^2 = .037$). Follow-up ANOVAs for each genotype group revealed a main effect of age at adoption in the Met group only ($F(1, 38) = 4.76$, $p < .05$, $\eta^2 = .111$). Within the Met

group, mean go trial accuracy was significantly higher for the early adopted group compared to the late adopted group (early adopted mean accuracy = 98.3%, sd = 2.0%, late adopted mean accuracy = 95.3%, sd = 5.2%). Neither group showed a significant effect of background when analyzed individually.

Go trial reaction time. A 2 (age at adoption) x 2 (genotype) x 4 (background) mixed-model ANOVA with IQ entered as a covariate revealed a main effect of background ($F(2.6, 205.2) = 3.28$, $p < .05$, $\eta^2 = .037$. Paired-samples t-tests were used to perform *post hoc* contrasts between the four background types. Results showed significantly longer reaction times on negative background trials than on scrambled ($t(82) = 12.40$, $p < .001$), neutral ($t(82) = 11.38$, $p < .001$), and positive ($t(90) = 9.09$, $p < .001$) trials. Scrambled trials were also found to have shorter response times relative to both positive ($t(90) = 6.41$, $p < .001$) and neutral ($t(90) = 5.09$, $p < .001$) trials.

Effect of IQ: summary. With the exception of the loss of significant effects of background in the accuracy measures, the addition of IQ as a covariate did not change results regarding the effect of age at adoption and genotype on go-nogo performance.

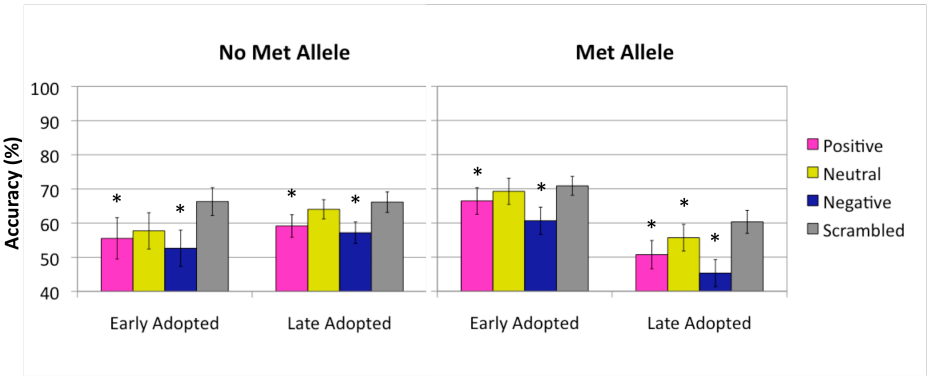

Figure 25. Accuracy on nogo trials for each genotype group, divided by age at adoption and background type.

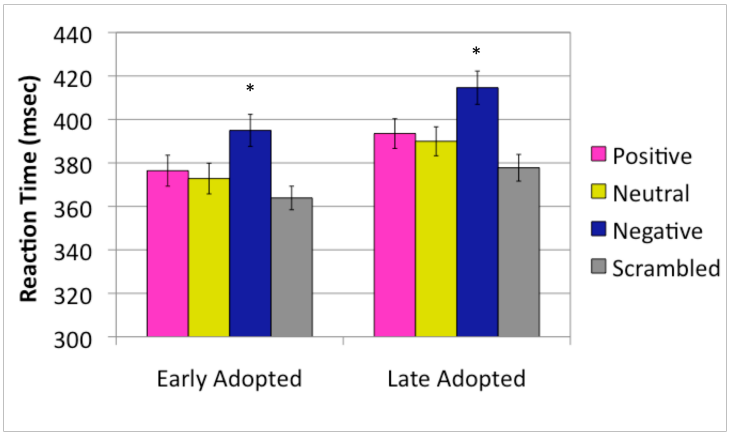

Figure 26. Reaction times on correct go trials for early versus late adopted participants on each background type.

Discussion

Findings in this study lend support to the hypothesis that increased duration of institutionalization during early development negatively affects inhibitory control during emotional distraction. However, this effect appeared only in the subgroup of participants with at least one met allele of the BNDF gene. That is, while the NoMet (val/val) group showed no effect of age at adoption, the Met group (val/met and met/met) showed higher nogo trial accuracy in adolescents adopted before twelve months of age versus adolescents adopted at twelve months of age or later. Furthermore, while individuals in the NoMet group showed decreased nogo accuracy on negative versus neutral trials only, the Met group showed lower accuracy on negative trials relative to all three other background types.

The sample as a whole showed all predicted effects of background on nogo accuracy. That is, while accuracy was significantly lower on negative trials relative to all other background types, accuracy on positive trials was significantly lower than on both neutral and scrambled trial, and neutral trials, in turn, showed significantly lower accuracy than scrambled trials. Thus, accuracy was affected incrementally by neutral, positive and negative background images. This pattern has been reflected in that majority of the go-nogo results, although in many cases only some of these background effects reached significance. In the original behavioral study (chapter 1), this full pattern was seen in the reaction time results. However, the internationally adopted sample is the first to display a full set of background effects on nogo accuracy. This may be due to heightened sensitivity to distraction in this population, although the absence of a true

control group makes this difficult to determine. Likewise, this sample showed decreased accuracy between the first and final runs of the task for both nogo and go accuracy, effects not seen in this age range in the previous studies. However, given the lengthier set of tasks completed by the internationally adopted adolescents during their session, it is inappropriate to conclude that this fatigue or boredom effect is driven by early institutional care.

Further analysis of accuracy on go trials showed a main effect of background in which negative trials showed lower scores compared to all other trial background types. However, follow-ups to the three-way age at adoption by genotype by background interaction revealed significant effects of background only in the late-adopted Met group. This finding again suggests that a combination of late adoption from institutional care and possession of at least one met allele is associated both with lower overall accuracy on the go-nogo task, but also increased sensitivity to distracting emotional backgrounds.

Reaction time measures, in contrast, indicated clear effects of background across all groups, with reaction times being slowest on negative trials and fastest on scrambled ones. This pattern is similar to that seen in the previously described studies where accuracy differences were seen only in the younger groups but reaction time effects appeared across all age groups. Thus, while negative background images did slow responding across groups, individuals who were adopted later and possessed a met allele were more likely to have background information interfere with their ability to withhold impulsive responding during the go-nogo task.

While attempts were made during recruitment to balance country of origin, genotype, gender and age at adoption in this sample, it must be acknowledged that these

features are not entirely balanced. In particular, the early-adopted Met group is composed almost entirely of Southeast Asian girls (see Table 6) while both late-adopted groups are predominantly European. In addition to cultural differences between these populations, there also exists a clear difference in the incidence of the met allele within the general population. While approximately 20% of Europeans possess a copy of the met version of the val66met polymorphism, this allele is considerably more common in Southeast Asia, being present in approximately 50% of the population. Therefore, it is possible that this version of the BDNF gene does not show the same deleterious effects in this population as in ones in which it is less common.

The higher IQ scores of the Met group are difficult to account for and this result is driven largely by the very high scores attained by some of the early adopted individuals. This difference, however, does not translate into generally better performance on the go-nogo task in the Met group. Rather, possession of a met allele seems to increase susceptibility to environmental influences, with early adopted individuals in this group performing very well, while late adopted individuals perform quite poorly on the task. Much less influence of duration of institutionalization, however, is seen in the val/val group. It is possible, then, that possession of a met allele is not only a risk factor when paired with negative life circumstances, but also a predictor of more general plasticity, that can be either adaptive or maladaptive during development.

Much more needs to be known about interactions between BDNF and other genes as well as between BDNF genotype and numerous environmental factors, before the sequelae of this polymorphism can be well understood. Nevertheless, these results present intriguing effects suggesting a role for both early environmental stress and

genotype in predicting how readily an adolescent may cope with distracting emotional input under circumstances where cognition and action must be carefully controlled.

General Discussion

Adolescence is typically considered to be bounded by puberty at its onset and the assumption of adult social roles at its end. Thus, it is both a biological and a cultural phenomenon, defined by a confluence of physiological, neurological and social factors (Spear, 2000a). The development of emotional and behavioral self-regulation is a central developmental task of adolescence. The ability to self-regulate permits increasing independence. In order to successfully transition from childhood to adulthood, adolescents must learn to navigate complex social situations that are often imbued with powerful emotions. In order to achieve long-term positive goals, avoid negative outcomes and conform to social rules, it is often necessary to delay, inhibit or alter an emotional response by either conscious or unconscious means. These skills are mediated by the interaction of cognitive and emotional processes. Decision-making and goal-directed behaviors are guided by both gut feelings and conscious consideration. In fact, even conscious "logical" decision-making is frequently influenced by emotional biases and unconscious computations of relative risk and reward (Bechara, Demasio, Demasio, & Lee, 1999). Adolescents face the daunting task of making significant life decisions with potential long-term consequences under the influence of volatile emotions and slowly developing executive functions.

Adolescence has long been conceived of as a period of turbulent emotionality and the concept of adolescent "storm and stress" has likewise become embedded in the rhetoric of much developmental psychology. This concept has even come to permeate public conceptions of what it means to be a teenager. Adolescence is, in fact, often a

period of high stress and frequently includes a number of experiences that give rise to strong and often conflicting emotions (Dahl, 2001). Rule-breaking, social status-seeking, and early romantic relationships are just a few examples of emotion-provoking events in adolescence. Furthermore, both risk-taking behaviors and psychopathological problems associated with adolescence can often be linked to both intense emotions and errors of self-regulation: either an overregulation, as in depression and anxiety, or an underregulation, as in substance abuse and conduct problems. Both sorts of errors can be connected to the still developing interface between emotion and cognition.

Adolescent mood changes and seemingly associated lapses of good judgment have been frequently attributed to the hormonal changes of puberty. Some evidence supports a relationship between the production of gonadal hormones in early adolescence and negative affect (Brooks-Gunn, Garber, & Paikoff, 1994) as well as emotional volatility (Buchanan, Eccles, & Becker, 1992). However, the amount of variance actually accounted for by hormonal differences is relatively small (Buchanan et al., 1992). A more complete model of the foundations of adolescent cognitive and emotional changes must address the influence of both life experience and ongoing neurological development. Recent studies have begun to explore the neural substrates of executive functions in adolescence compared to other developmental periods (Hooper et al., 2004; Huizinga et al., 2006; Eigsti et al., 2006). A few of these have examined executive ability during the processing of emotional information (Hare et al., 2008; Ladouceur et al., 2005; Monk et al., 2003). However, many questions regarding the development of cognition-emotion interactions during adolescence remain unaddressed.

The four studies included in this dissertation contribute to our understanding of how emotional information, even when it is not relevant to a given executive task may still influence behavior. Results of the first behavioral go-nogo study suggest that emotion is indeed disruptive to inhibitory control during early adolescence. This pattern of results fits well with a two-process model in which puberty-related emotional changes in early adolescence pose a particularly large challenge to still immature executive functions. However, while it might be argued that the 13-14 year-old participants showed the most dramatic disruptive effect of negative emotional images on inhibitory control, all three of the youngest age groups in this study demonstrated increased impulsive errors on negative trials. The youngest group also showed diminished accuracy on the emotionally positive trials, which posed no problem for any of the other age groups. It is therefore difficult to determine from these results whether the disruption seen in response inhibition is specific to the pubertal years, or whether it is part of a more linear developmental process in which both cognitive and emotional regulatory abilities increase gradually with age. Analysis of these data in relation to pubertal status versus age may help clarify this question.

The fMRI results in the second study point towards age-related functional differences in recruitment of prefrontal cortex during attempts to ignore emotional distraction. However, unlike some previous studies (Hare et al., 2008; Monk et al., 2003), no age-related differences were evident in limbic activation, supporting a more executive function-based model of adolescent developmental behavior changes. That is, age-related differences detected in this study underline the importance of selective and efficient recruitment of prefrontal circuits that provide top-down control of perception,

cognition, and action. Adults, but not adolescents, in this study recruited prefrontal cortex more for positive and negative images, compared to neutral ones. Adolescents, in contrast, showed increased activation for neutral versus scrambled images and did not show the same kind of selective activation for emotional versus non-emotional images. Communication between prefrontal regions and the rest of the brain, including limbic regions, are thought to be increasingly myelinated throughout adolescence. During this period inefficient synaptic connections are also eliminated and neural circuitry refined. This improved efficiency of communication between prefrontal cortex and the rest of the brain likely allows the selective recruitment of prefrontal cortex when task demands increase, as when emotionally distracting stimuli are presented. As in the first study, results underline the importance of gradually increasing regulatory abilities in determining adolescent behavior.

The third study presents results that suggest emotional distractors may interact differently with different cognitive tasks that tax different forms of executive function. While negative images were consistently the most disruptive during the go-nogo task, results were considerably more variable during the n-back. Furthermore, the addition of emotional distractors reduced the correlation between performance on these two executive tasks. Neutral and scrambled images, however, did not show this effect. It is thus quite possible that emotional information influences efforts at inhibitory control and efforts to maintain and manipulate information in working memory in distinct ways. In both cases, however, the introduction of emotional distractors did disrupt executive function in early adolescence. While some indices of this disruption declined with age (e.g. nogo trial accuracy) others showed more consistent effects across adolescence and

into early adulthood (e.g. increased reaction times on negative trials). The pattern of increasing disruption by emotional distractors across all age groups when the difficulty of the cognitive task increased suggests that age differences are due to increases in general regulatory capacity rather than changing impact of emotional information. This conclusion was further supported by the absence of differences in subjective ratings of the images. Thus, when cognitive resources were drained by a difficult executive task, all age groups were susceptible to distraction by the emotional images.

The fourth study began to explore potential interacting environmental and genetic influences on the relationship between emotion and executive function in adolescence. Results revealed poorer go-nogo performance and increased disruption by emotional images in young adolescents who were exposed to longer periods spent in stressful environments and who possessed a met version of the val66met polymorphism in the BDNF gene. While this study does not examine developmental changes, it underlines the roles of both biology and environment in predicting successful regulatory efforts under emotional circumstances during adolescence. It is not yet clear, however, whether these individual differences are driven by changes in regulatory abilities or in emotional reactivity. Given the broad neurological impact of early stress and BDNF availability, it is likely that differences exist in both emotion-processing and regulatory areas of the brain. Innumerable other questions remain as to what predicts which adolescents will have problems with emotional information interfering with critical cognitive processes.

Potential follow-ups to the current studies include research on other possible predictive factors, including other forms of life stress and a variety of genotype differences. It would also be useful to introduce and explore the influence of other forms

of emotional distraction. For example, a direct comparison of the disruptive effect of facial expressions of emotion versus IAPS images would begin to address questions regarding whether social-emotional signals are particularly salient and/or disruptive during adolescence. A departure from the use of static images would also be useful, as the presentation of a picture does not replicate the actual experience of guiding action while experiencing more endogenous emotions. The use of video, mood induction or constructed scenarios may provide more insight on adolescents' cognitive performance during emotion processing and regulation.

On a more technical side, the use of physiological measurements (such as the heart rate and galvanic skin response measures collected during the third study) could provide insight into the level at which emotional responding or regulation differ between younger and older adolescents. Given the reliance of emotional regulatory processes on cortico-limbic connections, DTI data examining white matter tracts as well as the use of connectivity analysis of fMRI data could inform us regarding neural correlates of better and worse emotion regulation during a cognitive task as well as age-related changes in these pathways.

Though cognition and emotion have been traditionally viewed as distinct, separable entities, modern psychological and neuroscientific research continues to demonstrate multiple, inextricable links between the two phenomena. One such link is seen when an organism must actively control its behavior, in spite of conflicting affective input, in order to accomplish adaptive goals. In particular, social interactions require the constant updating and integration of both emotional and non-emotional information along with the continual regulation of affect and attention in order to respond in an appropriate

and adaptive manner. Such integrative and regulatory challenges are particularly salient during the adolescent years, as individuals in this age group must navigate new, complex and emotionally loaded social scenarios. Furthermore, teens increasingly take on responsibility for their own behavioral regulation as they move towards independence and adulthood. It is thus not altogether surprising that there is considerable evidence that brain areas critical to executive functioning undergo significant maturation during the adolescent period. The influences of adolescent changes in emotion processing on executive functioning, however, are not yet well understood. This emotion-cognition interaction is likely to be critical to how well individuals fare in the face of the social challenges of adolescence and thus may be a key component to their ongoing well-being, competence and mental health.

It is important to note, however, that emotion is not inherently at odds with the ability to reason. Though folk-wisdom teaches us that emotions are irrational and disruptive, their existence would be difficult to explain if they did not serve an evolutionarily adaptive function. Emotions allow the rapid mobilization of multiple physiological subsystems and co-ordinated behavior patterns in response to aversive and appetitive stimuli in the environment. These 'gut' instincts serve as the basis for much of our real life decision-making: emotional flags, or somatic markers, provide rapid, unconsciously conveyed, information about the threat or reward associated with particular environmental cues (Bechara et al., 1999). At times, however, the affective reactions produced by such markers could potentiate socially inappropriate behaviors or decisions that would be contrary to the individual's long-term goals. Thus, it is necessary to have a cognitive override in place for when autonomic arousal must be actively

dampened or ignored so that cultural rules can be respected and social interactions can be negotiated successfully. More generally, affective regulatory systems allow the adaptive modulation of emotional experience and its associated behaviors so that an individual can achieve a desired goal (Dahl, 2001).

Although the current research takes some steps towards elucidating the changing relationship of emotion and executive function in adolescence, there is currently a need to continue characterizing both biological and environmental factors that affect, in particular, the interactions between affective regulation and cognitive functioning. Such research could help identify areas of risk for possible deviations from normative pathways and potentially aid in the design of interventions that could provide strategies to improve affect regulation and executive control during this volatile stage of life.

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Appendix I: Means and standard deviations for main behavioral measures

All values presented as mean(standard deviation).

EXPERIMENT 1

	NoGo Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	56.3(19.0)	60.1(15.4)	52.9(17.7)	63.8(15.0)	68.2(14.1)	59.3(18.9)
13-14	74.8(10.8)	73.8(11.5)	64.3(13.6)	77.3(9.7)	78.2(10.2)	76.4(11.6)
15-16	81.2(11.9)	81.5(10.9)	75.8(14.1)	79.4(9.5)	78.8(11.1)	80.0(10.5)
18-19	83.1(11.7)	83.1(10.2)	80.4(14.7)	83.5(9.6)	83.3(9.6)	83.8(11.5)
20-25	88.4(12.3)	89.5(5.6)	87.7(9.6)	89.5(9.0)	90.5(9.1)	88.5(10.4)

	Go Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	97.0(5.8)	98.4(3.4)	95.4(6.6)	98.1(2.7)	98.1(2.9)	98.1(2.9)
13-14	99.4(0.7)	99.0(1.4)	98.6(1.7)	99.5(0.6)	99.2(1.1)	99.9(0.4)
15-16	99.4(1.0)	99.8(0.4)	99.0(1.4)	99.6(0.5)	99.5(0.8)	99.8(0.4)
18-19	99.4(1.6)	99.0(2.9)	98.9(2.6)	99.3(1.6)	99.4(1.3)	99.2(2.7)
20-25	100.0(0.2)	99.9(0.4)	99.2(1.3)	99.4(0.9)	99.4(1.0)	99.4(1.3)

	Correct Go Trial Reaction Time					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	401(75)	399(73)	416(88)	390(63)	406(66)	375(64)
13-14	391(36)	390(35)	404(40)	378(25)	386(24)	370(31)
15-16	360(19)	363(23)	376(24)	354(21)	361(27)	347(23)
18-19	366(56)	366(57)	378(54)	361(54)	369(60)	353(50)
20-25	368(31)	368(32)	385(37)	364(23)	372(29)	356(25)

EXPERIMENT 2

	NoGo Trial Accuracy			
Age Group	Positive	Neutral	Negative	Scrambled
13-14	61.4(12.3)	61.1(14.5)	58.6(15.3)	60.8(16.1)
20-22	75.9(13.8)	78.6(13.1)	74.6(13.6)	77.3(13.0)

	Go Trial Accuracy			
Age Group	Positive	Neutral	Negative	Scrambled
13-14	98.6(2.1)	98.9(1.5)	98.7(2.0)	98.6(2.5)
20-22	98.8(1.5)	99.0(2.3)	98.8(2.0)	99.1(1.7)

	Correct Go Trial Reaction Time			
Age Group	Positive	Neutral	Negative	Scrambled
13-14	360(30)	357(26)	379(32)	342(30)
20-22	365(36)	365(29)	382(35)	361(24)

EXPERIMENT 3

GO-NOGO

	NoGo Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	57.0(17.1)	58.0(19.1)	51.4(18.5)	62.5(16.8)	65.8(18.7)	59.3(18.9)
13-14	73.4(15.9)	72.0(15.1)	68.4(17.6)	73.7(13.4)	74.2(13.7)	73.0(15.7)
15-16	74.9(16.4)	80.3(11.2)	75.0(15.7)	79.2(11.5	77.7(12.5)	80.7(15.2)
18-25	87.9(7.7)	85.1(9.1)	85.3(13.0)	88.9(8.5)	86.9(8.6)	90.5(10.8)

	Go Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	98.2(2.9)	98.5(2.8)	95.8(4.3)	97.9(2.3)	97.9(3.0)	97.7(3.5)
13-14	99.2(2.1)	99.1(2.2)	98.2(2.6)	98.9(1.3)	98.8(1.8)	99.1(1.3)
15-16	99.2(1.5)	99.6(1.1)	99.2(1.6)	99.5(1.3)	99.2(2.1)	99.8(1.0)
18-25	99.5(1.5)	99.2(2.1)	98.7(2.4)	99.2(1.8)	98.7(3.6)	99.8(0.7)

	Correct Go Trial Reaction Time					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	400(45)	386(44)	408(45)	385(38)	389(41)	380(41)
13-14	383(43)	385(47)	398(39)	375(39)	375(33)	374(48)
15-16	377(45)	377(46)	385(52)	374(40)	376(43)	371(42)
18-25	391(40)	385(39)	404(48)	379(36)	376(42)	382(40)

N-BACK

	0-Back Match Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	77.0(26.9)	88.0(23.0)	78.0(30.0)	86.1(21.4)	89.0(22.9)	83.0(26.7)
13-14	88.0(21.8	92.0(21.3)	90.0(21.7)	91.6(20.3)	94.0(20.8)	89.0(22.9)
15-16	95.8(12.0)	95.8(9.5)	92.7(13.8)	95.4(9.5)	95.8(12.0)	94.8(10.4)
18-25	92.7(15.6)	95.8(9.5)	97.7(7.1)	95.0(8.8)	99.0(5.1)	90.6(17.8)

	2-Back Match Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	55.3(29.5)	55.3(26.7)	55.3(27.1)	62.4(26.1)	61.4(27.5)	63.3(68.5
13-14	64.7(24.2)	71.9(24.4)	65.4(25.8)	72.7(20.1)	72.0(24.4)	73.3(24.5)
15-16	73.6(18.9)	75.6(23.1)	67.4(21.2)	75.5(14.6)	77.1(16.0)	73.5(19.6)
18-25	78.4(24.8)	81.9(26.8)	79.1(25.2)	80.5(8.05)	81.2(18.5)	79.8(21.9)

	3-Back Match Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	44.7(27.1)	51.4(30.7)	41.2(25.0)	51.4(21.2)	51.4(26.4)	51.3(26.2)
13-14	52.0(30.8)	64.7(21.6)	51.9(26.9)	58.9(20.4)	63.3(24.5)	54.7(23.3)
15-16	58.3(25.6)	53.4(24.1)	50.7(23.8)	64.9(17.6)	59.1(17.0)	70.8(23.1)
18-25	66.6(28.1)	63.1(27.4)	56.3(24.4)	67.8(19.8)	68.0(24.1)	67.4(21.2)

	0-Back Non-Match Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	93.8(20.0)	93.3(20.0)	94.0(20.1)	93.4(19.7)	91.3(20.3)	95.3(19.9)
13-14	95.5(20.0)	94.8(20.0)	94.8(19.9)	95.3(19.9)	95.3(19.9)	95.3(19.9)
15-16	100.0(0.0)	99.5(2.4)	99.0(2.9)	99.4(1.2)	99.0(2.3)	99.8(1.2)
18-25	98.8(3.1)	99.5(1.7	99.8(1.2)	98.9(1.7)	98.8(2.5)	99.0(2.9)

	2-Back Non-Match Trial Accuracy (No Xs)					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	84.8(21.2)	87.6(22.8)	86.8(22.9)	86.0(20.2)	88.4(20.8)	83.6(22.9)
13-14	86.4(21.2)	90.8(20.8)	90.0(21.4)	89.6(19.9)	88.4(21.2)	90.8(20.6)
15-16	92.1(9.8)	95.4(6.6)	92.9(14.9)	92.3(8.3)	89.6(12.3)	95.0(8.3)
18-25	98.3(3.8)	98.3(3.8)	96.3(5.8)	96.0(5.1)	96.7(5.6)	95.4(7.2)

	3-Back Non-Match Trial Accuracy (No Xs)					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
11-12	79.6(21.3)	83.2(20.1)	75.2(19.4)	86.0(20.2)	82.4(18.8)	85.2(21.8)
13-14	82.0(21.2)	86.0(20.4)	82.8(20.9)	89.6(19.9)	80.4(20.9)	85.2(21.4)
15-16	90.8(7.8)	90.4(9.1)	88.8(10.8)	92.3(8.3)	86.3(15.8)	92.9(8.6)
18-25	89.6(10.8)	95.0(6.6)	92.1(7.2)	96.0(5.1)	91.3(7.4)	90.8(11.4)

EXPERIMENT 4

	NoGo Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
Early	61.5(22.9)	64.0(21.2)	57.0(21.1)	68.8(16.4)	69.6(15.9)	68.1(17.6)
Late	55.4(18.5)	60.3(16.8)	51.9(18.2)	63.5(15.8)	65.0(16.4)	62.0(17.6)

	Go Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
Early	98.1(2.2)	98.3(2.8)	96.8(4.5)	97.6(3.6)	97.8(3.1)	97.6(4.6)
Late	96.7(4.7)	97.2(4.3)	95.3(6.3)	96.8(3.9)	97.7(3.7)	96.0(5.2)

	Correct Go Trial Reaction Time					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
Early	376(46)	373(46)	395(48)	364(35)	373(38)	354(36)
Late	394(48)	390(47)	415(54)	378(43)	382(44)	373(47)

	NoGo Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
No Met	57.7(21.3)	61.4(18.7)	55.3(19.3)	66.2(16.4)	67.3(17.6)	65.2(17.3)
Met	58.8(20.4)	62.6(19.4)	53.2(20.1)	65.7(15.4)	66.9(15.0)	64.4(18.5)

	Go Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
No Met	97.4(3.6)	97.9(3.3)	96.5(5.3)	97.6(3.2)	98.5(2.3)	96.8(4.9)
Met	97.2(4.2)	97.5(4.1)	95.5(5.8)	96.8(4.3)	97.0(4.2)	96.8(5.1)

	Correct Go Trial Reaction Time					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
No Met	393(52)	389(51)	412(59)	377(42)	385(44)	368(45)
Met	378(41)	375(41)	399(43)	366(37)	372(38)	360(42)

	NoGo Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
Early-NM	55.5(26.4)	57.7(23.1)	52.6(23.1)	66.3(17.7)	66.7(19.6)	66.1(19.0)
Late-NM	59.1(17.2)	64.0(14.7)	57.2(16.3)	66.1(15.6)	67.8(16.4)	64.6(16.3)
Early-M	66.4(18.6)	69.3(18.4)	60.7(19.1)	70.9(13.3)	72.0(12.0)	69.7(16.7)
Late-M	50.7(19.4)	55.7(18.3)	45.3(18.5)	60.3(15.8)	61.6(16.2)	58.9(19.0)

	Go Trial Accuracy					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
Early-NM	97.9(2.1)	98.4(3.0)	95.8(6.1)	97.4(4.0)	98.0(3.0)	96.9(5.7)
Late-NM	97.0(4.3)	97.5(3.6)	97.0(4.8)	97.7(2.6)	98.8(1.6)	96.7(4.4)
Early-M	98.3(2.4)	98.3(2.6)	97.6(2.4)	97.8(3.3)	97.7(3.3)	98.2(3.5)
Late-M	96.2(5.3)	96.7(5.2)	93.2(7.3)	95.7(4.9)	96.3(5.0)	95.3(6.0)

	Correct Go Trial Reaction Time					
Age Group	Positive	Neutral	Negative	Scrambled	Run 1	Run 3
Early-NM	374(56)	371(57)	395(62)	364(43)	377(48)	350(43)
Late-NM	407(46)	401(44)	425(54)	386(40)	390(41)	381(42)
Early-M	378(38)	374(35)	395(34)	364(28)	370(29)	358(30)
Late-M	377(46)	376(47)	402(51)	368(45)	373(46)	363(52)

Appendix II: Significant differences in BOLD activation for reported MRI contrasts

Adults

Region	Side	BA	Talairach Coordinates			t-value
			x	y	z	df = 11
Negative > Neutral						
Amygdala	R		24	-4	-7	10.04
Amygdala	L		-21	-5	-8	9.73
Caudate	L		-10	3	10	4.70
Caudate	R		10	3	12	4.54
Fusiform Gyrus	R	37	40	-46	-13	8.91
Fusiform Gyrus	L	37	-41	-52	-13	7.96
Hypothalamus	R		7	-5	-1	7.29
Inferior Parietal Lobule	R	39	43	-65	10	10.48
Inferior Parietal Lobule	L	39	-40	-68	18	9.40
Inferior Temporal Gyrus	L	37	-43	-71	0	8.17
Medial Frontal Gyrus	B	10	-3	49	-3	5.82
Medial Frontal Gyrus	L	9	-5	47	33	5.51
Middle Frontal Gyrus	R	8	39	11	30	7.88
Middle Temporal Gyrus	L	21	-57	-6	-11	6.58
Nucleus Accumbens	B		1	2	3	5.60
Posterior Cingulate Gyrus	L	23	-5	-51	27	5.04
Superior Parietal Lobule	R	7	27	-71	32	7.21
Negative < Neutral						
Hippocampus	R		23	-38	10	-8.95

Negative > Neutral

Region	Side	BA	Talairach Coordinates			t-value
			x	y	z	df = 27
Adults > Adolescents						
Hypothalamus	R		4	-1	3	4.33
Inferior Parietal Lobule	L	7	-31	-53	45	4.23
Medial Frontal Gyrus	B	8	2	33	48	4.63
Middle Frontal Gyrus	L	6	-29	6	45	3.84
Middle Frontal Gyrus	R	8	46	16	43	4.42
Middle Frontal Gyrus	R	10	38	56	11	4.56
Superior Frontal Gyrus	L	6	-5	-12	65	4.22
Superior Frontal Gyrus	R	6	31	6	53	4.12
Superior Parietal Lobule	R	7	34	-51	45	3.45
Supramarginal Gyrus	R	40	39	-59	30	4.94

Positive > Neutral

Region	Side	BA	Talairach Coordinates			t-value
			x	y	z	df = 27
Adults > Adolescents						
Anterior Cingulate Gyrus	R	32	6	25	32	4.19
Globus Pallidus	R		8	-1	5	4.16
Inferior Frontal Gyrus	R	44	53	10	21	3.73
Inferior Parietal Lobule	R	40/7	38	-54	44	4.15
Ligual Gyrus	R	18	16	-60	1	3.70
Medial/Superior Frontal Gyrus	B	6	0	-3	55	4.78
Middle Frontal Gyrus	R	6	43	7	42	5.21
Middle Frontal Gyrus	R	8	33	13	26	4.34
Middle Frontal Gyrus	R	10	30	48	4	4.63
Postcentral Gyrus	L	1	-28	-31	59	3.66
Precuneus	R	7	18	-69	30	3.9
Superior Parietal Lobule	L	7	-24	-49	57	4.08
Superior Parietal Lobule	L	7	-22	-67	36	3.71
Superior Parietal Lobule	L	7	-34	-47	44	4.63
Superior Temporal Gyrus	L	22	-43	-50	11	3.58
Superior Temporal Gyrus	R	22	44	52	10	4.52
Adults < Adolescents						
Middle Frontal Gyrus	R	8	43	31	34	-4.66

Neutral > Scrambled

Region	Side	BA	Talairach Coordinates			t-value
			x	y	z	df = 27
Adult < Adolescents						
Fusiform Gyrus	L	37	-40	-50	-17	-4.68
Fusiform Gyrus	R	19	36	-66	-6	-4.38
Lingual Gyrus	R	19	17	-57	-1	-4.71
Lingual Gyrus/Precuneus	L	18	-18	-59	2	-4.00
Medial Frontal Gyrus	B	8	3	33	47	-4.37
Middle Frontal Gyrus	L	46	-40	44	4	-4.82
Middle Frontal Gyrus	R	6	37	5	41	-3.50
Middle Frontal Gyrus	R	9	45	18	33	-4.40
Middle Temporal Gyrus	L	21	-56	-33	-11	-5.22
Middle Temporal/Angular Gyrus	L	39	-44	-71	10	-4.05
Superior Parietal Lobule	L	7	-28	-70	39	-4.24

Scrambled > Scrambled All-Go

Region	Side	BA	Talairach Coordinates			t-value
			x	y	z	df = 27
Adults < Adolescents						
Fusiform Gyrus	R	18	37	-83	-18	-4.67
Lingual Gyrus	R	18	16	-97	-11	-3.68
Paracentral Lobule	L	4	-6	-35	63	-3.84
Postcentral Gyrus	R	7	11	-48	62	-4.84
Precuneus	B	7	-1	-58	40	-4.56