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Inhibitory Control During Emotional Distraction Across Adolescence and Early Adulthood

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Abstract

This study investigated the changing relation between emotion and inhibitory control during adolescence. One hundred participants between 11 and 25 years of age performed a go-nogo task in which task-relevant stimuli (letters) were presented at the center of large task-irrelevant images depicting negative, positive, or neutral scenes selected from the International Affective Picture System. Longer reaction times for negative trials were found across all age groups, suggesting that negative but not positive emotional images captured attention across this age range. However, age differences in accuracy on inhibitory trials suggest that response inhibition is more readily disrupted by negative emotional distraction in early adolescence relative to late childhood, late adolescence or early adulthood.

Social and cognitive demands change dramatically during adolescence as individuals become independent from their caregivers 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 begin early in the second decade of life (Arnett, 1999; Dahl, 2001; Romeo, 2003; Spear, 2000; Steinberg, et al., 2006). During this same period, the regulatory cognitive capacities necessary for overriding intense emotions and desires develop slowly, not reaching adult levels until a decade or so after affective changes begin (Spear, 2000). The gap between the onset of emotional changes and the full maturation of inhibitory control may contribute to a window of risk for emotional dysregulation and potentially deleterious impulsive actions in early adolescence.

Inhibitory control is a critical executive skill that allows individuals to withhold maladaptive impulsive responses in favor of successful goal-directed behavior. Performance on a variety of tasks requiring response inhibition has been found to improve steadily throughout adolescence including antisaccade tasks (Luna & Sweeney, 2004), Stroop tasks (Adelman, et al., 2002; Huizinga, Dolan, & van der Molen, 2006; Marsh, et al., 2006) and go-nogo tasks (Eigsti, et al., 2006; Hooper, Luciana, Conklin, & Yarger, 2004). In parallel with these increases in inhibitory capacity, structural and functional neuroimaging data show continued development across adolescence in frontal brain circuits critical to successful cognitive control (Casey, Jones, & Hare, 2008; Durston, et al., 2006; Giedd, et al., 1999; Gogtay, et al., 2004; Luna, Padmanabhan, & O'Hearn, 2010; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999; Sowell, Trauner, Gamst, & Jernigan, 2002; Toga, Thompson, & Sowell, 2006). The relatively late consolidation of such neural circuits may contribute to poor impulse regulation in adolescence. This lack of effective inhibitory control, in turn, can lead to dangerous risk-taking behaviors commonly observed in adolescence, such as drunk driving, illicit drug use, and unprotected sex. Thus, a better understanding of inhibitory control

during adolescence and the factors that contribute to its disruption is of considerable value to public health.

In addition to limited impulse control, many adolescents contend with heightened emotional intensity and volatility (Arnett, 1999; Buchanan, Eccles, & Becker, 1992; Petersen, et al., 1993; Steinberg, et al., 2006). Adolescents, relative to other age groups, report increased mood variability, increased self-consciousness, reduced positive affect and increased duration and potency of negative emotions (Larson & Ham, 1993; Petersen, et al., 1993). In fact, studies employing self-report scales have found as many as 20-50% of adolescents meeting conventional adult criteria for clinically significant depression (Kessler, Avenevoli, & Merikangas, 2001; Petersen, et al., 1993). Though interview-based studies report more modest rates of adolescent depression (Kessler & Walters, 1998), adolescence is unquestionably a period of elevated risk for the onset of mood disorders and other forms of psychopathology. Many of these disorders, including depression, social anxiety, eating disorders and substance abuse, feature altered emotional responding and insufficient or maladaptive emotion regulation as key symptoms.

Gender differences in psychopathology also emerge during the early teen years (Angold, Costello, & Worthman, 1998; Kessler, et al., 2001). Among the most salient changes is the shift from equal incidence of depression in girls and boys during late childhood, to a much higher prevalence of depression in adolescent girls relative to their male peers (Angold, Erkanli, Silberg, Eaves, & Costello, 2002). Male adolescents, however, are more likely than females to show increased severity of conduct problems during adolescence and are more likely to engage in criminal activity such as vandalism and petty theft (Steinberg, et al., 2006). Thus, it is clear that the emotional changes that occur during adolescence are not equivalent for both genders. The timing and gender disparities of these emotional changes suggest a role for pubertal hormones and their effects on both body and brain. However, among both healthy and disordered populations, only a small portion of the variability in adolescent emotional experience can be accounted for by hormonal changes (Brooks-Gunn, Garber, & Paikoff, 1994; Brooks-Gunn & Warren, 1989) and the etiology of adolescent mood changes continues to be the source of much speculation. Further variability may be due to cognitive and neurological development during this period.

Emotions must frequently be regulated cognitively in order to permit adaptive behavior, such as when anger must be controlled or temptation avoided. To date, only a few studies have attempted to measure the impact of emotion on inhibitory control in healthy adolescents. Studies using facial expressions of emotion as stimuli in a go-nogo task have found slower responding to fear faces in adolescents compared to adults (Hare, et al., 2008), as well as steady improvements in both emotion discrimination and inhibitory control in the presence of emotional stimuli across adolescence (Tottenham, Hare, & Casey, 2011). A similar go-nogo study reported a linear reduction in impulsive errors with age on neutral cues while adolescents showed proportionally higher impulsive errors on positive trials relative to both children and adults (Somerville, Hare, & Casey, 2011). Results from neuroimaging studies have also suggested developmental changes in the impact of emotion on cognitive control during adolescence. These findings include increased activation of emotion-processing limbic areas in adolescents relative to other age groups in response to fearful faces, both during a go-nogo task (Hare, et al., 2008), and during passive viewing (Monk, et al., 2003). Increased activity in regulatory regions in the same age group has been observed when the task required ignoring emotional aspects of the stimulus (Monk, et al., 2003). Elevation in an ERP index of inhibitory demands (the N2 component) has been found in adolescents but not children in response to a negative emotion induction during performance of a go-nogo task (Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006). Together, these behavioral and imaging studies suggest heightened sensitivity to emotional

information during performance of inhibitory control tasks during adolescence relative to other ages. However, the majority of these tasks require participants to identify facial expressions of emotion, an ability that may also change across adolescence (McGivern, Andersen, Byrd, Mutter, & Reilly, 2002; Thomas, et al., 2001), making it difficult to distinguish between the disruption of inhibitory control by the presence of emotional content and developmental changes in the identification and interpretation of facial expressions. Furthermore, most existing studies on the interaction of emotion and inhibitory control in adolescence have not examined potential differences in effects of emotional stimuli at multiple age points within adolescence, a far from homogeneous developmental period.

The current study aims to further characterize the changing interface between inhibitory control and emotion during normative adolescent development. Specifically, we examine potential differences in the impact of task-irrelevant emotional background images on inhibitory control in a go-nogo task in multiple age groups across adolescence and into early adulthood. By subdividing adolescence into multiple age groups, we aimed to discern whether go-nogo performance was more disrupted by distracting emotional content during the early adolescent period during which many emotional changes occur. Alternately, the disruptive quality of the images could decrease gradually between childhood and adulthood as inhibitory control matures. We hypothesized that the presence of emotional images (negative or positive) compared to nonemotional images (neutral or scrambled) would disrupt performance to some extent in all age groups. We further predicted that this disruption would be largest in the 13 to 14 year old group, for whom emotional changes were underway and regulatory systems were still far from mature. We also expected that the disruptive effect of emotional information may differ for males and females within the early to mid-adolescent age groups, given the marked gender differences in emotional development during adolescence. Such results would support the idea that the disruption of cognitive control systems by emotional input may be elevated in early adolescence relative to other ages and that this disruption may arise from an interaction between gradually maturing regulatory cognitive systems and changes in emotional reactivity.

Method

Participants

One hundred participants were included in the sample (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). Young 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 through the Institute of Child Development at the University of Minnesota from a list of local families who had expressed interest in research opportunities for their children. The recruited sample was approximately 90% Caucasian, 6% Asian, 3% African American and 1% other. Adolescents were paid for their participation and parents were compensated for travel expenses. All participants were pre-screened for previously diagnosed neurological and psychological disorders, including alcohol and substance abuse or dependence as well as serious medical issues and learning disabilities. While at the lab, participants completed a series of standardized questionnaires that probed anxiety levels (State-Trait Anxiety Inventory [STAI] or State-Trait Anxiety Inventory – Child [STAI-C]), attention skills (Conner's Adult ADHD Rating Scales [CAARS or Conner's Parent Rating Scale) and general functioning (Symptom Checklist – 90 [SCL-90] or Achenbach Child Behavior Checklist [CBCL] and Youth Self-Report [YSR]). The SCL-90 includes subscales measuring somatization, obsessive-compulsive symptoms, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation and psychoticism, while the CBCL and YSR include measures of depression,

somatic complaints, social problems, thought problems, attention problems, rule-breaking behavior, and aggressive behavior. Participants who scored within the clinical range, as defined by available norms on each measure, on any subscale of these questionnaires were removed from subsequent data analyses and replaced with new participants to produce the final sample of 100. Due to this secondary screening, 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. No participants were excluded based on task performance. All recruitment and experimental procedures were approved by the Institutional Review Board of the University of Minnesota.

Behavioral Task

The behavioral paradigm combined an inhibitory control task (the go-nogo) with negative, positive and neutral images selected from the International Affective Picture System (IAPS: (Lang, Bradley, & Cuthbert, 2008)). In this task, letters were presented sequentially in a small box at the center of the computer screen while IAPS images were displayed in the background. Participants were instructed to ignore the emotional images and respond as quickly as possible with a button press to every one of the letters, except for a specific nogo stimulus: 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 responses during nogo trials. The task required sustained vigilance as well as conscious control of a potentiated behavior.

The IAPS is a collection of images selected to span a wide range of content. Each of these images has been rated by a large sample of adults using a scale from one to nine for each of two emotional dimensions: arousal, ranging from not arousing (1) to highly arousing (9), and valence, ranging from unpleasant or negative (1) to pleasant or positive (9). Normative ratings of the entire IAPS stimulus set 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 images (erotica, mutilation images, and some violent scenes) were removed from the set. From the remaining images, we selected 120 different images with highly positive valence ratings (average valence rating = 7.32, average arousal rating = 4.94), 120 images with highly negative valence ratings (average valence rating = 3.12, average arousal rating = 5.32), and 120 images 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 groups of interest, it was not possible 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 or valence, each of the selected IAPS images was scrambled using a 32×32 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" × 0.4") containing a black letter appeared in the center of the screen. Both letter and background image remained on the screen for an additional 650 ms, completing the trial (See Figure 1). Images were presented alone, prior to presentation of the letter stimulus in order to make it more difficult for participants to ignore picture content.

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.

Participants completed the task in five runs of 120 trials. Participants were given breaks to rest their eyes after each run. In all five runs, letter stimuli were presented in random order with the restriction that five Xs occurred within each set of 20 trials. Beyond this, there was no restriction on how many Xs could appear in a row. In *runs one and five*, the background images were scrambled images derived from the IAPS stimulus set. These scrambled runs were used to examine possible age differences in practice and fatigue effects in the absence of emotional background content. Throughout *runs two, three, and four*, backgrounds were non-scrambled IAPS images. 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 images were grouped into blocks of twenty unique images each depicting the same valence: positive, negative or neutral. This ensured that across the entire block, all participants were reasonably likely to respond in the expected valence direction and experience the intended emotional state. Within the twenty-trial valence block, the order of image presentation was randomized. Within each run of 120 trials, two blocks of each of the three valences was presented. The order of valence blocks was counterbalanced across participants. In order to reduce habituation to the background images, each IAPS image was presented only once during the task.

Pubertal Status Measure

Participants were asked to complete the Petersen Pubertal Development Scale (Petersen, Crockett, Richards, & Boxer, 1988), a self-report scale for pubertal status. This questionnaire consists of five questions about specific puberty-related physical changes (e.g. growth spurt, body hair, skin changes). Each question was answered on a 4-level ordinal response scale with the exception of a question about menstruation for girls, which is necessarily dichotomous (scored as either 1 or 4). This scale was not completed by participants over 18 years of age.

Data Analysis

Reaction time and response accuracy data for both go and nogo trials were recorded for each participant in all five runs of the task. Accuracy on inhibitory (nogo) trials was used as our primary measure of inhibitory control. Successful discrimination between go and nogo targets was measured using d' , computed by subtracting the z -transformed false alarm rate from the z -transformed hit rate: $d' = z(H) - z(F)$. Reaction times on correct go trials were analyzed as an index of attention capture by the background image. Each measure was analyzed via mixed model ANOVAs including age group (11-12, 13-14, 15-16, 18-19, 20-25 years) as a between subject factor 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 revealed by the ANOVAs were followed up with *post hoc* tests that were Bonferroni corrected to account for multiple comparisons. For comparison to other background conditions, performance on scrambled trials was computed by averaging performance in runs one and five. Practice or fatigue was measured by subtracting performance on run five from performance on run one for each outcome measure.

Relations between age, pubertal scores and task performance were also examined via hierarchical linear regression. Relations between clinical questionnaire measures and

performance were also explored via linear regression. Assumptions of normality, linearity, and equality of variance were met in all cases.

Results

Effects of Age and Gender on Inhibitory Control

Effects of fatigue or practice on nogo trial accuracy were examined via a 5 (age group) $\times$ 2 (gender) ANOVA. Practice or fatigue was measured by subtracting nogo accuracy on run five from nogo accuracy on run one for each subject. Results revealed a main effect of age group ($F(4, 90) = 2.74, p = .034, \eta^2 = .108$). No other significant effects were found. Follow-up contrasts between each age group (10 contrasts, $\alpha = .005$) revealed no significant differences. However, given a significant main effect of age on practice or fatigue, this measure was entered as a covariate in subsequent analyses.

The influence of age, gender and distracting emotional information on nogo accuracy was examined using a 5 (age group) $\times$ 2 (gender) $\times$ 4 (background) mixed model ANCOVA with fatigue entered as a covariate. The ANCOVA revealed main effects of background ($F(3, 267) = 15.85, p < .001, \eta^2 = .151$) and age group ($F(4, 89) = 18.90, p < .001, \eta^2 = .459$). Results also showed a significant background $\times$ age group interaction ($F(12, 267) = 2.36, p = .007, \eta^2 = .096$), as well as a three-way background $\times$ age group $\times$ gender interaction ($F(12, 267) = 1.82, p = .045, \eta^2 = .076$). Nogo trial accuracy for each age group and background is presented in Figure 2a and Table 1.

In order to further explore the three-way interaction effect, a 2 (gender) $\times$ 4 (background), mixed model ANOVA was performed for each of the five age groups ($\alpha = .01$). These separate ANOVAs showed no main effects of gender, but found a main effect of background in the 13-14 year-old ($F(3, 51) = 14.59, p < .001, \eta^2 = .462$) and 15-16 year-old ($F(3, 51) = 4.63, p = .006, \eta^2 = .214$) age groups. No significant effect of background was found in the 11-12, 18-19, or 20-25 year-old age groups. In the 15-16 year-old age group only, an interaction effect between background and gender was also found ($F(3, 51) = 7.52, p < .001, \eta^2 = .307$).

The main effect of background in the 13-14 year-old group was followed up using six paired-samples *t*-tests ($\alpha = .008$). These comparisons revealed significant differences between negative background trials and scrambled ($t(19) = 6.19, p < .001$), neutral ($t(19) = 3.91, p = .001$) and positive ($t(19) = 3.69, p = .002$) trials, with lower accuracy on negative trials in each case.

In order to explore the background $\times$ gender interaction in the 15-16 year-old age group, performance on each background type was compared via six paired-samples *t*-tests ($\alpha = .008$) for each gender within this group. These analyses revealed that females performed significantly worse on negative trials relative to scrambled ($t(9) = 3.77, p = .004$) and neutral trials ($t(9) = 3.49, p = .007$). In contrast, males in this group showed no significant differences in nogo accuracy based on trial background type. Nogo trial accuracy for each gender in the 15-16 year-old age group, subdivided by background, is presented in Figure 2b.

Effects of Age and Gender on Stimulus Discrimination

Effects of fatigue and practice on d-prime were examined via a 5 (age group) $\times$ 2 (gender) ANOVA. Results revealed no significant effects. Thus, this measure was not included as a covariate in the subsequent d-prime analyses.

The influence of age and distracting emotional information on target discrimination, as measured by d-prime, was examined via a 5 (age group) $\times$ 2 (gender) $\times$ 4 (background) mixed model ANOVA. Results indicated main effects of both background ($F(3,270) = 45.02, p < .001, \eta^2 = .333$) and age group ($F(4,90) = 25.79, p < .001, \eta^2 = .534$) as well as a background $\times$ gender interaction ($F(3, 270) = 3.47, p = .017, \eta^2 = .037$) and a background $\times$ age group interaction effect ($F(12, 270) = 2.12, p = .016, \eta^2 = .086$). A strong trend was seen for a three-way, background $\times$ age group $\times$ gender interaction ($F(12, 270) = 1.78, p = .052, \eta^2 = .073$) but this effect did not reach significance. D-prime values for all age groups and backgrounds are presented in Figure 3 and Table 2.

The background $\times$ gender interaction was followed up using two repeated measures ANOVAs, one for each gender, with background as a between-subject variable. Results showed highly significant effects of background in both gender groups: females ($F(3, 147) = 32.59, p < .001, \eta^2 = .399$) and males ($F(3, 147) = 11.90, p < .001, \eta^2 = .195$). For each gender group, paired-samples t-tests were used to contrast performance on each of the background types (6 pairwise comparisons, $\alpha = .008$). For females, d-prime values on negative trials were found to be significantly lower than on all three other background types: positive ($t(49) = 3.98, p < .001$), neutral ($t(49) = 5.02, p < .001$), and scrambled ($t(49) = 8.81, p < .001$). Values were also significantly higher for scrambled trials relative to both positive ($t(49) = 6.41, p < .001$) and neutral ($t(49) = 4.54, p < .001$) ones. Males displayed a similar pattern of results, with performance on negative trials being significantly poorer than on positive ($t(49) = 3.68, p = .001$), neutral ($t(49) = 2.79, p = .007$), and scrambled trials ($t(49) = 5.50, p < .001$). Performance on scrambled trials was also significantly higher compared to neutral trials ($t(49) = 3.05, p = .004$), though the difference between scrambled and positive trials did not reach significance. Independent-samples t-tests contrasting performance between males and females for each background type revealed no significant gender differences in d-prime.

The background $\times$ age group interaction was followed up using five repeated measures ANOVAs, one for each age group, to look at the effects of trial background on d-prime. Using a significance criteria of $\alpha = .01$ to correct for multiple comparisons, significant effects of background were found in all but the eldest age groups: 11-12 years ($F(3,57) = 18.51, p < .001, \eta^2 = .494$); 13-14 years ($F(3,57) = 18.29, p < .001, \eta^2 = .491$); 15-16 ($F(2,0,38.1) = 7.01, p = .003, \eta^2 = .270$); 18-19 ($F(3,57) = 5.13, p = .003, \eta^2 = .213$). For each of these four age groups, paired-samples t-tests were used to contrast discrimination on each of the background types ($\alpha = .008$). In the 11-12 year-old group, d-prime was found to be significantly lower for negative relative to all three other background types: positive ($t(19) = 3.02, p = .003$); neutral ($t(19) = 4.62, p < .001$); and scrambled ($t(19) = 6.15, p < .001$). This group also showed significantly lower d-prime values for positive relative to scrambled trials ($t(19) = 5.19, p < .001$). In the 13-14 year-old group, d-prime was found to be significantly lower for negative relative to positive ($t(19) = 4.25, p < .001$) and scrambled ($t(19) = 7.10, p < .001$) trials. In this age group, d-prime values were also significantly higher on scrambled trials compared to positive ($t(19) = 4.73, p < .001$) and neutral ($t(19) = 3.87, p = .001$) trials. In the 15-16 year-old group, d-prime was significantly lower on negative relative to scrambled trials only ($t(19) = 3.78, p = .001$). Likewise, in the 18-19 year-old group d-prime for negative trials was significantly lower than for scrambled trials ($t(19) = 3.12, p = .006$). This group also showed significantly lower d-prime values for neutral relative to scrambled trials ($t(19) = 3.19, p = .005$). In summary, in all but the eldest group, where no significant effects were seen, d-prime values were highest in the scrambled background condition and lowest in the negative background condition, with values on positive and neutral conditions falling in-between. The two youngest age groups showed significant differences between the negative condition compared to positive and neutral conditions that were not seen in the older groups.

Effects of Age and Gender on Reaction Time

A 5 (age group) $\times$ 2 (gender) ANOVA was used to examine group differences in the effects of fatigue and practice on go trial reaction time. No significant effects were found, so this variable was not included in subsequent analyses.

In order to examine the effects of age and emotion on go trial reaction time, a 5 (age group) $\times$ 2 (gender) $\times$ 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 ($F(4, 90) = 2.51, p = .048, \eta^2 = .100$). There were no significant interaction effects. Mean reaction times for all age groups and background types are presented in Table 3 and Figure 4.

The main effect of age group was followed up using ten *post hoc* contrasts ($\alpha = .005$). However, no significant differences between individual age groups were found. Descriptively, reaction times improved from age 11 to 16, with no appreciable improvements beyond that age. The main effect of background was explored further via six paired-samples *t*-tests ($\alpha = .008$), comparing reaction times for each background type. These tests revealed that reaction times were significantly longer for negative trials compared to scrambled ($t(99) = 10.47, p < .001$), neutral ($t(99) = 8.08, p < .001$), and positive ($t(99) = 9.63, p < .001$) trials. 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 ($t(99) = 4.76, p < .001$).

Puberty and Task Performance

Puberty scores were found to be highly correlated with age ($r = .75, p < .001$). Hierarchical regressions performed for each performance measure (nogo accuracy, d-prime and reaction time) on each background condition (negative, positive, neutral, scrambled), showed no significant predictive value of pubertal score beyond age. Within the adolescent sample (ages 11-16 years) from whom pubertal scores were collected, age consistently showed higher correlations with performance on all measures and in all conditions than did pubertal score.

Associations between Task Performance and Questionnaire Measures

Standardized questionnaires were administered mainly as a screening tool, used to detect and exclude participants who were experiencing clinical levels of psychopathological symptoms in the absence of a formal diagnosis. However, a number of the measures derived from these questionnaires tap into constructs that are potentially relevant to task performance, even within a normative range of scores. These possible relations were explored via regression analyses. Because different, age appropriate measures were administered to subjects under age 18 years versus 18 and over, regression analyses were performed separately for these two age groups.

In the adolescent sample (ages 11-16 years), the following questionnaire measures were included in the regression analyses: state anxiety and trait anxiety scores from the STAI-C, cognitive impulsivity and ADHD scores from the Conner's Parent Rating Scale, and anxious-depressed, withdrawn-depressed, and affective problems measures from the YSR. Of these measures, state anxiety was found to predict nogo accuracy in the negative ($F(1,58) = 5.47, p = .023, \text{adjusted } R^2 = .070$) and positive ($F(1,58) = 5.94, p = .018, \text{adjusted } R^2 = .077$) background conditions, with accuracy increasing in each case with increased reported state anxiety. No other significant relations were found between questionnaire measures and task performance measures in this age group.

In the adult group (18-25 years), analyses included the following questionnaire measures: state and trait anxiety scores from the STAI, inattention and impulsivity scores from the CAARS, and depression, anxiety and phobic anxiety scores from the SCL-90. As in the adolescent group, state anxiety was found to predict nogo accuracy on negative ($F(1,38) = 6.27, p = .017$, adjusted $R^2 = .119$) and positive ($F(1,38) = 4.45, p = .042$, adjusted $R^2 = .081$) as well as scrambled ($F(1,38) = 6.31, p = .016$, adjusted $R^2 = .120$) background conditions. In this age group, however, accuracy *decreased* with increased state anxiety. Negative relations were also found between impulsivity scores and performance on positive trials as measured by both nogo accuracy ($F(1,36) = 5.10, p = .030$, adjusted $R^2 = .100$) and d-prime ($F(1,36) = 8.75, p = .005$, adjusted $R^2 = .173$). No other significant relations between questionnaire measures and task performance were found.

Discussion

Results of this study replicate previous research showing improvements in response inhibition with age throughout adolescence (e.g. Casey, et al., 1997; Durston, et al., 2002; Hooper, et al., 2004; Johnstone, Pleffer, Barry, Clarke, & Smith, 2005; Rubia, et al., 2006). This finding is consistent with a protracted development of inhibitory control that continues well into the adolescent years and contradicts suggestions that response inhibition is fully developed by the end of childhood (Paus, 2005; Paus, Keshavan, & Giedd, 2008).

Results of this study supported the prediction that younger adolescents, when required to exert inhibitory control over a potentiated response, are more readily disrupted by emotional information than are older adolescents and adults. Furthermore, emotional inputs appear to derail regulatory efforts more easily in this age range even when the emotion information is not directly relevant to the regulatory task. This effect, however, was limited to negative images. Positive images, conversely, did not significantly disrupt response inhibition, as measured by nogo trial accuracy in the age range tested. The lack of a significant impact of positive images on this aspect of task performance may be due to slightly lower arousal levels evoked by the positive relative to the negative images (4.94 on the versus 5.32, respectively on the Self-Assessment Manikin [SAM] scale) or could reflect the influence of an automatic orienting response to potentially dangerous stimuli on negative trials that is difficult to override (Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001). While other studies have reported increased disruption of inhibitory control by positive stimuli during adolescence (e.g. Somerville, et al., 2011), these studies have used emotional information such as facial expressions as the distinguishing factor between targets and non-target stimuli. Therefore, it is possible that the enhanced tendency observed in adolescence to approach these positive stimuli is more relevant when attention is deliberately focused on emotional content. Alternatively, such effects may be specific to social cues such as facial expressions of emotion. Results of the current study do suggest that adolescents may not have as much difficulty deliberately diverting attention away from positive information as they do with negative content, a hypothesis supported by some existing research (e.g. Monk, et al., 2003).

In the mid-adolescent group (ages 15-16 years) females were found to have poorer inhibitory control during distraction by negative emotional information while males of the same age showed no effect of emotional backgrounds on nogo accuracy. This result closely parallels findings in the clinical literature that show marked gender differences in the prevalence of depression and anxiety symptoms in early to mid adolescence (Angold, et al., 2002; Ge, Lorenz, Conger, Elder, & Simons, 1994; Kessler, et al., 2001). This finding suggests a possible difficulty ignoring emotionally negative information in pubertal females that can impact cognitive control. Such a negative information processing bias, particularly in association with reduced inhibitory control, could influence mood and constitute a risk factor for multiple forms of psychopathology. Multiple studies have established the

contribution of emotional information processing in the risk for mood disorders in adulthood (see Mathews & MacLeod, 2004 for review) and some data suggest a negative processing bias may also contribute to the risk for such disorders in adolescence, particularly among girls (Dagleish, et al., 2003; Joormann, Talbot, & Gotlib, 2007; Taghavi, Neshat-Doost, Moradi, Yule, & Dagleish, 1999). Studies have also found that performance on emotional go-nogo tasks differs between healthy and clinically depressed or anxious adolescents (Han, et al., 2012; Ladouceur, et al., 2006). Similar performance effects have been found between healthy and mood disordered adolescents on a memory task in which IAPS images were used as backgrounds for letter stimuli (Ladouceur, et al., 2005). Evidence of a change in emotional information processing in this study and its deleterious impact on inhibitory control within a healthy population of young adolescents suggests one possible mechanism contributing to the elevated risk of psychopathology within this age group.

It is worth noting, however, that relations found between the clinical questionnaire measures of depressive and anxiety symptoms and task performance were minimal in the adolescent group. Furthermore, state anxiety measures were found to correlate with improved accuracy on inhibitory trials within the adolescent group. This counterintuitive effect might be the result of young participants who are more anxious in the research setting being more invested in performing well while under a researcher's observation, but this conclusion is highly speculative. The limited range of variability in questionnaire measures may account for the absence of significant relations between other mood and attention measures and performance. Results in the adult group were more intuitive, showing increases in impulsive errors with increased ratings of state anxiety and impulsivity.

Unlike inhibitory control, successful discrimination of go and nogo stimuli, as measured by d-prime, showed significant differences due to background emotion in all but the eldest age group. This pattern of findings suggests that the presence of images, and negative images in particular, does render this go-nogo task more difficult for individuals up through age 19, at least, though performance on the four background types becomes increasingly similar with increasing age (see Figure 3). Unlike inhibitory control, target discrimination appears to be affected by the presence of any discernable image in most of the groups, indicated by better performance on scrambled trials relative to picture trials.

Differences in average reaction time on go trials revealed relatively little in the way of developmental change. Despite an overall main effect of age group, individual comparisons of reaction times between age groups revealed no significant differences. This is most likely because the relatively large within-group variability rendered more subtle between-group differences more difficult to detect. Descriptively, reaction times appear to improve with age until reaching a plateau around 15-16 years of age. Across age groups, negative trials showed significantly slower reaction times relative to all other trial types while scrambled trials showed significantly faster reaction times. This pattern of results suggests that the negative images were at least somewhat salient in all five age groups. The slowed responding on the negative trials suggests that these images captured attention to a greater degree across the studied age range, including early adulthood. The key difference however, is that the older age groups were still able to maintain high rates of nogo trial accuracy, even while distracted by the negative emotional information. This pattern of results suggests that age-related accuracy differences on negative versus other trial types are less likely a consequence of the emotional stimuli being more salient in the younger age groups and more likely an indication of an immature capacity for cognitive control in emotionally distracting situations. This result provides insight into the cognitive mechanisms at play when adolescents must regulate behavior in day-to-day situations where unrelated emotion may prevent optimal cognitive functioning and decision-making.

Limitations and Future Directions

It is not clear from the current study whether the increased disruptiveness of negative images in the 13-14 year-old 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 age groups. Future studies of the neural and physiological correlates of these differences should help clarify the contributions of immature regulatory abilities and increased emotionality to this effect. However, emotional reactivity and emotion regulation are such intrinsically interwoven and mutually influential processes that their contributions to behavior are extremely difficult to distinguish. It is likely that both factors influence performance to some degree.

Another shortcoming of the current study was the use of a self-report based measure of pubertal status as opposed to a physical exam or hormonal measures. While the Peterson scale has been shown to be moderately correlated with physiological and hormonal measures of puberty, and is less uncomfortable for adolescent subjects, more direct pubertal measures could provide more nuanced information on the role of puberty in emotional and cognitive changes.

The presentation of scrambled trials only in the first and last runs of the task was designed to allow for the detection of age differences in fatigue and practice effects between age groups. However, this distribution of trials makes comparisons between scrambled and non-scrambled trials more difficult. Placement and the beginning and end of the task likely increased the impact of practice and fatigue on scrambled relative to other trial types. Nevertheless, performance on these trials was consistently better than on those presenting coherent images, even in the absence of significant practice effects, suggesting that the absence of a coherent image made for an easier task.

Future studies would likely benefit from inclusion of measures of alcohol and drug use, given the relevance of substance use to inhibitory control, particularly in adolescence. While only a small number of adolescent subjects reported drinking without parental supervision and only one reported illicit drug use, frequency and magnitude of use were not measured. Alcohol and drug use was not measured in the young adult sample, where it was likely more common.

Ultimately, this study only addresses a single measure of inhibitory control, and more specifically the inhibition of a prepotent motor response. Naturally, impulsive decisions and actions taken by adolescents in their day-to-day lives are governed by more complex and nuanced mechanisms than those that govern performance of a go-nogo task. Factors such as the ability to weigh options, resolve conflicting inputs, and consider immediate versus more distant future rewards likely contribute to adolescent behavior and continue to mature well beyond childhood. Personally relevant emotions are also more likely to impact behavior, compared to the presentation of emotional images – though our reactions to such images may vary based on personal relevance. Nevertheless, this protocol, despite its relative simplicity, does reveal potentially meaningful age and gender differences in inhibitory control during emotional distraction.

Conclusion

This study contributes to our understanding of how emotional information, even information that is irrelevant to a given executive task, may still influence behavior. In this study, behavioral changes in response inhibition and 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 relation between neurological development and adolescents' ability to control their behavior under emotional

circumstances. Emotional and behavioral self-regulation are central developmental tasks of adolescence (Dahl, 2001). In order to successfully transition from childhood to adulthood, adolescents must learn to navigate complex social situations that are often imbued with powerful emotions (Arnett, 1999). Rulebreaking, social status-seeking, and early romantic relationships are just a few examples of emotion-provoking events in adolescence. 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 (Asato, Terwilliger, Woo, & Luna, 2010; Casey, et al., 2008; Luna, et al., 2010). The influences of adolescent changes in emotion processing on executive functioning, however, are not yet well understood. 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. 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 (Fox, Henderson, Marshall, Nichols, & Ghera, 2005), or an underregulation, as in substance abuse and conduct problems (Nigg, 2000; Schweinsburg, et al., 2004). Both sorts of errors may derive from the dependence of regulatory efforts on a still developing, immature, interface between emotion and cognition. This emotion-cognition interaction is therefore 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. Although the current research takes some steps towards elucidating the changing relation of emotion and executive function in adolescence, there is a need for continued characterization of both biological and environmental factors that affect the interactions between emotion regulation and cognitive functioning. Such research may further identify areas of risk for deviations from normative pathways and aid in the design of interventions that could provide strategies to improve affect regulation and executive control during this frequently volatile stage of life.

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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 pictured here). Scrambled versions of these images were used as backgrounds in control blocks.

Figure 2.

Accuracy on nogo trials. a) Accuracy for all age groups and background types. Accuracy was significantly worse on negative trials versus all three other trial types in the 13-14 year-old age group. No significant main effects of emotion were found in the 11-12, 18-19 or 20-25 year-old age groups. b) Accuracy on nogo trials for females and males in the 15-16 year-old age group. This age group showed both a significant main effect of emotion and a gender $\times$ emotion interaction. Females performed significantly worse on negative trials relative to scrambled and neutral trials. Males in this age group showed no significant differences in nogo accuracy based on trial background. No other age groups showed a significant overall effect of background. Error bars show standard error (SE). * $p < .01$

Figure 3.

D-prime for all age groups and background types. Effects of trial background were seen in all but the oldest age group on this measure. The four younger groups all showed significantly poorer discrimination on negative versus scrambled background conditions. The two youngest groups (11-12 and 13-14 years) also showed significantly poorer discrimination on negative relative to positive and neutral conditions. Additionally, the 13-14 and 18-19 year old groups showed significantly better performance on scrambled versus neutral conditions and the 13-14 year-old group alone also showed significantly better performance on scrambled relative to positive background trials. Error bars show standard error (SE).

*significantly different from negative, $p < .01$; *significantly different from scrambled, $p < .01$.

Figure 4. Reaction times on correct go trials for all age groups and background types. A main effect of background suggests that reaction times were significantly longer for negative trials relative to positive, neutral and scrambled trials across the age range studied. Error bars show standard error (SE).

Table 1
Accuracy (%) on Nogo Trials for all Age Groups and Backgrounds: Mean (SD)

Age Group	Negative	Positive	Neutral	Scrambled
11-12	52.9(17.7)	56.3(19.0)	60.1(15.4)	63.8(15.0)
13-14	64.3(13.6)	74.8(10.8)	73.8(11.5)	77.3(9.7)
15-16	75.8(14.1)	81.2(11.9)	81.5(10.9)	79.4(9.5)
18-19	80.4(14.7)	83.1(11.7)	83.1(10.2)	83.5(9.6)
20-25	87.7(9.6)	88.4(12.3)	89.5(5.6)	89.5(9.0)

Table 2
D-Prime Values for all Age Groups and Backgrounds: Mean (SD)

Age Group	Negative	Positive	Neutral	Scrambled
11-12	1.91(0.73)	2.20(0.67)	2.41(0.49)	2.59(0.65)
13-14	2.50(0.50)	2.91(0.36)	2.86(0.45)	3.22(0.32)
15-16	2.95(0.55)	3.20(0.55)	3.23(0.46)	3.33(0.42)
18-19	3.12(0.54)	3.26(0.48)	3.22(0.44)	3.46(0.43)
20-25	3.47(0.50)	3.63(0.56)	3.58(0.33)	3.79(0.53)

Table 3
Reaction Time (msec) Data for all AgeGroups and Backgrounds: Mean (SD)

Age Group	Negative	Positive	Neutral	Scrambled
11-12	416 (88)	401 (75)	399 (73)	390 (63)
13-14	404 (40)	391 (36)	390 (35)	378 (25)
15-16	376 (24)	360 (19)	363 (23)	354 (21)
18-19	378 (54)	366 (56)	366 (57)	361 (54)
20-25	385 (37)	368 (31)	368 (32)	364 (23)