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Reactive and proactive control in incarcerated and community adolescents and young adults

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Abstract

This study compared the cognitive control skills of male incarcerated adolescents ($n=44$), male control adolescents ($n=33$), male incarcerated young adults ($n=41$), and male control young adults ($n=35$) using the AX-Continuous Performance Task. This task measures proactive control (the ability to maintain a mental representation of goal-related information in preparation for a behavioral response) and reactive control (the ability to activate goal-related information in response to an external trigger). Incarcerated individuals had more difficulty implementing proactive control, whereas control individuals had more difficulty implementing reactive control. Adolescents had more difficulty with both reactive and proactive control compared to young adults, suggesting that both skills improve with age. Additional analyses indicated that the effect of age on proactive control was due to the presence of attention-deficit/hyperactivity disorder, whereas the effect of age on reactive control appeared to be a natural developmental trend that could not be explained by other variables. These findings are considered in relation to the dual mechanisms of control theory (Braver, Gray, & Burgess, 2007).

Society has long acknowledged differences in the decision-making abilities of adults and children, reserving certain legal privileges such as voting, driving, and drinking alcohol for older individuals. The juvenile justice system was established on the rationale; although children may engage in legal transgressions, they lack criminal intent because of their age. Within such legal contexts, it has been suggested that the developmental immaturity of adolescents should mitigate criminal culpability (Scott & Steinberg, 2003; Steinberg & Cauffman, 2001; Steinberg & Scott, 2003).

Anecdotal evidence suggests that adolescents generally fail to consider the entirety of a situation when making decisions and instead are easily swayed by irrelevant or habitual influences. As adolescents mature into adults, they are expected to gain the ability to engage in deliberate and goal-directed behaviors even within a complex and distracting environment. Performance of goal-directed behaviors has been empirically linked to the prefrontal region of the brain (Liston, Watts, Tottenham, Davidson, Niogi, Ulug, & Casey, 2006; Tamm, Menon, & Reiss, 2002), which is still developing during adolescence (Casey, Galvan, & Hare, 2005; Spear, 2000). The prefrontal region has been associated with cognitive control skills such as memory, attention, and inhibition (Casey, Tottenham, & Fossella, 2002; Fuster, 1985), which also develop through adolescence (Luna & Sweeney, 2004; Luna et al., 2001).

Braver, Gray, and Burgess (2007) propose that when people activate information relevant to a goal, they are likely to behave in ways that are consistent with that goal. They suggest that

there are two distinct cognitive processes that activate goal-relevant information to enable behavioral control. The first, proactive control, biases the individual toward a behavioral response by actively maintaining goal-related information following a relevant cue. The second, reactive control, biases the individual toward a behavioral response by activating goal-related information derived from the environmental context at the time a behavioral decision is required. Behavioral decisions are therefore internally guided by proactive control and externally guided by reactive control.

To enhance understanding of cognitive control, we compared the cognitive skills of incarcerated adolescents, incarcerated young adults, control adolescents, and control young adults. We focused on the AX-Continuous Performance Test (AX-CPT), which has accumulated significant empirical support (Barch, Carter, MacDonald, Braver, & Cohen, 2003; Braver, Satpute, Rush, Racine, & Barch, 2005; MacDonald, Pogue-Geile, Johnson, & Carter, 2003) and is aptly suited to examine proactive and reactive control (Braver et al., 2007). We predict that those who have been incarcerated will be less likely to use proactive control but more likely to use reactive control, compared to those who have not been incarcerated. We also predict that adolescents will have poorer reactive control skills than young adults. To justify these hypotheses, we examine research on developmental changes in the prefrontal cortex (PFC) during adolescence, present evidence that cognitive control is linked to the PFC, highlight changes in cognitive control that occur with age, present evidence supporting the model of cognitive control used to examine reactive and proactive control in this study, and discuss empirical evidence that delinquency is linked to disruptions in cognitive control.

Development, the Prefrontal Cortex, and Cognitive Control

Many developmental changes to the PFC occur through late adolescence, making it one of the last areas of the brain to fully mature (Casey et al., 2005; Casey, Giedd, & Thomas, 2000). Cortical gray matter volume increases until adolescence, after which point it decreases, particularly in the PFC (Gogtay et al., 2004). During adolescence, white matter increases in the PFC (Reiss, Abrams, Singer, Ross, & Denckla, 1996), likely due to increased myelination of this brain region (Cummings, 1993). The combination of these two major developmental changes suggests that the operation of the PFC becomes more focused and efficient during adolescence (Casey, Tottenham, Liston, & Durston, 2005; Caviness, Kennedy, Richelme, Rademacher, & Filipek, 1996; Luna & Sweeney, 2004).

The changes in the PFC that occur during adolescence are important to the development of response inhibition skills. Investigators have found significant effects of age on a task measuring response inhibition, such that children perform such a task slower (Durston, Thomas, Yang, Uluğ, Zimmerman, & Casey, 2002; Tamm et al., 2002) and less accurately (Durston et al., 2002) than adults. Also, with age activation of the PFC becomes less broad and more localized to regions specific to response inhibition (Casey et al., 1997; Durston, Davidson, Tottenham, Galvan, Spicer, Fossella, & Casey, 2006; Luna et al., 2001; Tamm et al., 2002). Many of these investigations, however, have compared children and pre-adolescents to adults. It is therefore unclear whether these conclusions can be extended across adolescence.

Context Processing: Reactive and Proactive Cognitive Control

The inhibition of task-inappropriate responses requires the individual to maintain mental representations of task-relevant information in the presence of interference from competing information (Casey et al., 2002). These skills appear to be central to context processing, the ability to use task-relevant information to determine an appropriate behavioral response (Cohen, Barch, Carter, & Servan-Schreiber, 1999). task-relevant information that individuals rely on when determining an appropriate behavioral response. Successful context processing requires mental representations of context information to either be actively maintained during

periods of delay or be transiently represented in response to trigger events (Braver et al., 2007).

The AX-CPT is commonly used to examine such context processing abilities (Cohen et al., 1999; Barch, Carter, MacDonald, Braver, & Cohen, 2003). In this task, letters are individually and sequentially displayed on a computer screen, with pause between the presentations of each letter. Trials consist of cue-probe sequences of two consecutive letters. Participants are told for example, to respond to the letter *X* only when it is preceded by the letter *A*. Context information is presented by the cue (*A* or not *A*), which in turn biases responses to the probe (*X* or not *X*). This structure creates four types of trials: *AX* (where *A* is followed by *X*), *AY* (where *A* is followed by any non-*X* letter), *BX* (where any non-*A* letter is followed by *X*), and *BY* (where any non-*A* letter is followed by any non-*X* letter). Participants should only respond to *AX* trials; responses to other trials are incorrect.

In the AX-CPT, a mental representation of the context information must be maintained and updated in memory on a trial-by-trial basis to influence responses to the probe. Misuse of context information can create two response bias errors, expectancy bias and perceptual bias. Expectancy bias errors (Braver et al., 2005) occur when context information from the cue is an invalid predictor of a response to the probe. In the AX-CPT, these errors can be made on *AY* trials, where activation from the mental representation of the cue leads individuals to respond to the probe incorrectly. Perceptual bias errors, on the other hand, occur when individuals fail to inhibit dominant response tendencies to a probe (Braver et al., 2005). In the AX-CPT, *A* precedes *X* in 70% of the trials, creating an automatic tendency to respond to *X*. This tendency must be inhibited on *BX* trials. Failing to inhibit this response tendency causes perceptual bias errors.

Braver et al. (2007) proposed the Dual Mechanisms of Control (DMC) theory, claiming that different cognitive control strategies serve to minimize these two biases. *Proactive control* prevents perceptual bias errors by using environmental cues to actively formulate and retain a mental image of context information. This mental representation internally guides the individual's response when presented with a behavioral decision. However, individuals may commit expectancy bias errors when they are overly reliant on their internal representations to guide their behavior. In the AX-CPT, these errors occur when the individual responds (incorrectly) on *AY* trials. *Reactive control* prevents expectancy bias errors by using context information provided by the environment, externally activating goal-related information. This goal-related information is only transiently activated and directly influences decisions in response to the environmental context of that moment. Perceptual bias errors can be created when individuals are overly reliant on information from the immediate context to guide their behavior. In the AX-CPT, these errors occur when the individual responds (incorrectly) on *BX* trials. Although perceptual and expectancy errors on the AX-CPT task provide distinct estimates of reactive and proactive control, it is the consistent use of both strategies that is needed for successful cognitive control (Braver et al., 2007).

There are several important differences between proactive and reactive control (Braver et al., 2007). Proactive control is cue-driven, whereas reactive control is probe-driven. Proactive control requires the maintenance and activation of context information across periods of delay. Mental representations therefore internally guide one's behavioral decisions in proactive control. Reactive control, in contrast, externally activates goal-related information at the point a behavioral decision is required. When using reactive control, therefore, information from the immediate environment directly influences one's behavioral decisions regardless of the mental representations currently being maintained. Thus, determination of an appropriate behavioral response is internally guided by mentally represented context information from the past and externally guided by context information available in the environment at the time a decision

is required. There is preliminary empirical support for the distinction between reactive and proactive control. A neurocomputational model separating these two cognitive control functions successfully accounted for behavioral responses and brain imaging data in a study of response inhibition (DePisapia & Braver, 2006). Furthermore, Braver et al. (2005) found that older adults (mean age = 71.7 years) appeared to rely more on reactive control than younger adults (mean age = 18.9 years), suggesting that the use of proactive control may decrease with age to a greater extent than reactive control.

Individuals who have disruptions in the PFC have been shown to be less sensitive to context information, compared to healthy controls (Barch et al., 2003; Cohen et al., 1999; and MacDonald et al., 2003 for individuals with schizophrenia; Barch et al., 2003 for individuals with a psychotic disorder; Braver et al., 2005 for individuals with dementia of the Alzheimer's type). On the AX-CPT, these clinical samples perform more poorly on trials that require proactive control to overcome a perceptual bias (i.e., *BX* trials). We were interested in examining whether similar results would be found in incarcerated populations. Although context processing has not yet been examined among incarcerated individuals, prior research (Morgan & Lilienfeld, 2000) suggests that they may have limited cognitive control skills which could impair their performance on the AX-CPT.

The Current Study

There is strong empirical evidence that individuals who engage in delinquent and antisocial behaviors perform more poorly than control individuals on tasks measuring a variety of cognitive control skills (Lynam & Henry, 2001 and Teichner & Golden, 2000). Morgan & Lilienfeld (2000) meta-analyzed the literature on the relation between antisocial conduct and measures of executive functioning (e.g., response inhibition, attention, and memory). They found a significant relation (weighted mean $d = 0.62$) between antisocial behavior and executive functioning, with antisocial individuals performing more poorly than control participants. Several researchers have found that children and adolescents with conduct problems perform more poorly than control participants on tasks measuring response inhibition (Herba, Trannah, Rubia, & Yule, 2006; Toupin, Déry, Pauzé, Mercier, & Fortin, 2000), mental flexibility/set shifting (Kim, Kim, & Kwon, 2001; Lueger & Gill, 1990; Moffitt & Henry, 1989; Olvera, Semrud-Clikeman, Pliszka, & O'Donnell, 2005; Toupin et al., 2000), and sustained attention (Lueger & Gill, 1990; Moffitt & Henry, 1989; Toupin et al., 2000). Other researchers have found no difference between individuals with conduct problems and control participants on tasks measuring response inhibition (Déry, Toupin, Pauzé, Mercier, & Fortin, 1999; Kim et al., 2001), response planning (Déry et al., 1999; Toupin et al., 2001), attention (Déry et al., 1999; Kim et al., 2001), and memory (Kim et al., 2001). The vast majority of these executive functioning tasks measured broad cognitive control skills, which may account for these inconsistent findings. Differentiating cognitive control into reactive and proactive control may, therefore, provide further insight.

Here we use the AX-CPT to investigate the reactive and proactive cognitive control skills of four male samples—incarcerated adolescents, incarcerated young adults, control adolescents, and control young adults. Given the developmental changes in cognitive control skills through adolescence, we predicted that adolescents would have poorer reactive control skills (i.e., more false alarms in the *AY* condition) than young adults. Furthermore, prior research has shown that control samples make more expectancy bias errors compared to clinical samples (Braver et al., 2001; Braver et al., 2005; MacDonald et al., 2003), suggesting that the controls would have poorer reactive control skills. We therefore predicted that non-incarcerated individuals would show poorer reactive control than incarcerated individuals. Finally, we suspected that the predicted differences between our samples might be related to intelligence and/or the presence of attention-deficit/hyperactivity disorder (ADHD).

Method

Participants

Participants were (a) male adolescent offenders from a juvenile detention center ($n=44$), (b) young adult male offenders from a medium-security prison ($n=41$), (c) a control sample of adolescent males from the community, contacted through local schools and a housing authority ($n=33$), and (d) a control sample of young adult males from the University of Alabama ($n=35$). Six participants from the initial sample of 151 were excluded from analyses. One participant from the detention center and one participant from the prison were excluded because they failed to complete the experimental task. Two participants from the adult control sample were excluded because English was not their primary language. An additional two participants from the adult control sample were excluded because they had had legal charges as juveniles. Mean ages were 15.70 years ($SD = 1.67$) for the detained adolescents, 20.86 years ($SD = 1.47$) for the young adult prisoners, 14.52 years ($SD = 1.53$) for the community adolescents, and 19.34 years ($SD=2.93$) for the young adult controls. Thirty-five percent ($n = 15$) of the incarcerated adolescent sample was Caucasian and 65% ($n = 28$) was African-American. Twenty-seven percent ($n = 11$) of the incarcerated young adult sample was and 73% ($n = 29$). Sixty-one percent ($n = 21$) of the adolescent control sample was, 36% ($n = 12$), and 3% ($n = 1$) Hispanic. Eighty-four percent ($n=26$) of the young adult control sample was, 10% ($n=3$), 3% ($n=1$) was Hispanic, and 3% ($n=1$) of multiple ethnicities. English was the first language of all included participants.

All incarcerated young adults were volunteers who provided informed consent to participate in the study. Control adolescents and incarcerated adolescents provided informed assent and a parent or guardian provided informed consent. The adolescent controls and incarcerated adolescents were paid between \$10 and \$20 for their time. Their institution prohibited payment to the incarcerated young adults. The young adult controls received course credit for participating.

Procedure

All participants were tested individually by a trained research assistant. Tasks were administered on a computer using E-Prime (2002), a software package for conducting psychological experiments. A research assistant was available at all times to answer questions. Although participants were tested in different settings, all participants used equivalent stimulus response devices and had equivalent testing environments (e.g., levels of comfort, ease of responding). Testing sessions did not always occur in a distraction-free setting. A trained research assistant therefore used a standardized observation sheet to record the number of distractions that occurred during the task. Adding the number of distractions as a covariate, however in our analyses did not change the significance of any of our findings.

Measures

AX-Continuous Performance Test (AX-CPT; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). The stimuli in this task were letters that appeared individually, one after the other, on a computer screen. The task had an underlying cue-probe structure that consisted of two-letter sequences (e.g., *A* followed by *F*). Participants were not told of this structure, but instead were simply instructed to respond quickly and accurately to the letter *X* only when it appeared after the letter *A* (i.e., an *A-X* cue-probe sequence). Context information was provided by the cue (i.e., whether it was or was not an *A*), which in turn determined the appropriate response to the probe (i.e., responding or not responding to an *X*). A strong tendency to respond to *X* was induced by increasing the frequency of the *A-X* cue-probe combination to 70% of the trials. The remaining 30% of the trials were evenly distributed among *BX*, *AY*, and *BY* trials (Servan-

Schreiber, Cohen, & Steingard, 1996). The delay between the cue and the probe was manipulated to be either 1 second or 5 seconds.

Following procedures used in previous research (Barch et al., 2004; Barch et al., 2003; Braver et al., 2005), the inter-trial interval (ITI) was inversely related to the delay condition, yielding a 5 second ITI for the 1-second delay condition and a 1 second ITI for the 5-second delay condition. Inversely varying ITI across conditions controlled for the possible extraneous influences of general performance factors such as the amount of time spent on the task, frequency of responding, and task pace. Stimuli appeared on the computer screen for 300 ms in 24-point uppercase Helvetica font. Beginning with probe stimulus onset, participants had a 1300 ms interval in which to respond. All errors (responses in the *BX*, *AY*, and *BY* conditions and failures to respond in the *AX* condition) resulted in a dull sound. Hits in the *AX* condition resulted in a sharp clicking sound, indicating a correct response. No sound feedback was provided for correct rejections in the *BX*, *AY*, and *BY* conditions. A total of 400 trials occurred in 4 blocks of 100 trials each, with breaks provided between blocks. The cue-probe delay was manipulated between blocks, so that each block consisted either completely of short delay or completely of long delay trials. The order of blocks was counterbalanced across participants. Participant responses were recorded via mouse button presses. A practice block of 20 trials (10 short and 10 long delay) was given before test trials began to ensure that participants understood the task. Participants were required to attain 75% accuracy before they were given test trials.

Intelligence—Participants completed the Kaufman Brief Intelligence Test-(Second Edition) (K-BIT 2; Kaufman & Kaufman, 2004) to measure verbal and non-verbal intelligence. Composite scores on the K-BIT 2 have excellent internal consistency, reliability, and construct validity (Kaufman and Kaufman, 2004) and to correlate highly with full-scale IQ.

Socio-economic Status—Estimated socio-economic status was based on participants' reports of their parents' guardians highest level of education (1 = eight years or less, 2 = some high school, 3 = high school graduate, 4 = some college or technical school, 5 = college graduate). Parents'/guardians' educational levels were averaged if the individual lived with two parents or guardians.

Drug and Alcohol Use—Drug and alcohol use was measured with the Center for Substance Abuse Prevention (CSAP) youth survey. These items were modified to assess the frequency and amount of drugs and/or alcohol used during the individual's life time. Drugs covered on this measure included tobacco, alcohol, marijuana, and inhalants. The composite measure used in analyses indicated how many days per month the individual used these drugs. Only the incarcerated adolescents, control young adults, and incarcerated young adults completed this measure since none of the control adolescents had a history of drug or alcohol use. Adolescent controls were asked screening questions about drug and alcohol use (i.e., "Have you ever used drugs or alcohol, even just a taste or sip, in your life? For example, have you ever tried alcohol, marijuana, or cigarettes?"). None of the adolescent controls endorsed these screening items, and they were therefore not given the CSAP.

Diagnosis—Participants reported any currently diagnosed mental health disorders (depression, anxiety, ADHD), which was verified through medical files whenever possible. Only ADHD occurred frequently enough for statistically examination. Among those coded as diagnosed with ADHD, it was noted what medications were being taken at the time of testing.

Results

We first examined a signal detection measure, d' -context, specific to the AX-CPT task (Cohen et al., 1999; Servan-Schreiber et al., 1996). This measure was calculated using the formula d'

d' -context = $Z_{(AX \text{ hits})} - Z_{(BX \text{ false alarms})}$. Following the suggestion of Nuechterlein (1991), we substituted the value of 0.995 (calculated as $2^{-\left(\frac{1}{N}\right)}$, where N is the number of target trials) for 100% hit rates and 0.034 (calculated as $1 - 2^{-\left(\frac{1}{M}\right)}$, where M is the number of nontarget trials) for 0% false alarm rates to provide an unbiased estimation of d' -context. We analyzed d' -context using a mixed ANOVA with delay as a within-subjects factor and group as a between-subjects factor.

The main effect of delay was significant, $F [1,143] = 273.79, p < 0.001$, partial $\eta^2 = 0.66$, Wilks' Lambda = 0.34, with d' -context larger in the short-delay condition ($M = 3.90, SE = 0.06$) than the long-delay condition ($M = 3.02, SE = 0.08$). The main effect of sample was also significant, $F [3,143] = 3.92$, partial $\eta^2 = 0.08, p = 0.01$, with d' -context lower for incarcerated adolescents ($M = 3.12, SE = 0.11$) than control young adults ($M = 3.66, SE = 0.13, p < 0.01$). The incarcerated young adults ($M = 3.48, SE = 0.12$) did not differ significantly from incarcerated adolescents, control adolescents ($M = 3.56, SE = 0.13$), or control young adults. The two control samples were not significantly different from each other on d' -context. The two-way interaction between delay and group was not significant.

We conducted a mixed ANOVA to examine the effects of delay, condition, sample, and all possible interactions among these variables on arcsine transformed error rates $2 \times \arcsin[\sqrt{\text{error rate}}]$; Cohen, Cohen, West, & Aiken, 2003). Post-hoc comparisons were conducted for all significant effects using a Sidak (1967) correction for multiple comparisons. (see Table 1).

There was a significant main effect of condition, such that the mean error rates for the *AY* ($M = 0.12, SE = 0.01, p < 0.001$) and *BX* ($M = 0.11, SE = 0.01, p < 0.001$) conditions were significantly larger than for the *AX* ($M = 0.03, SE = 0.003$) and the *BY* condition ($M = 0.01, SE = 0.002$). The *BY* condition was significantly lower than the other three conditions (all p s < 0.001). The mean error rates for the *AY* and *BX* conditions were not significantly different from each other.

There was a significant two-way interaction between condition and sample (see Figure 1). In the *AY* condition (measure of reactive control), the mean error rate for control adolescents ($M = 0.16, SE = 0.02$) was significantly higher than that for incarcerated young adults ($M = 0.08, SE = 0.02, p = 0.05$), but not significantly different than that for the incarcerated adolescents ($M = 0.13, SE = 0.02$) nor for the control young adults ($M = 0.11, SE = 0.02$). In the *BX* condition (measure of proactive control), the mean error rate for incarcerated adolescents ($M = 0.19, SE = 0.02$) was significantly higher than for control adolescents ($M = 0.10, SE = 0.02, p = 0.009$), young adult prisoners ($M = 0.09, SE = 0.02, p = 0.003$), and control young adults ($M = 0.05, SE = 0.03, p < 0.001$). The mean *BX* error rates for control adolescents, control young adults, and incarcerated young adults were not significantly different from each other. There were no influences of sample on *AX* and *BY* error rates. The general pattern appears to be that the control samples have higher error rates in the *AY* condition, whereas the incarcerated samples have higher error rates in the *BX* condition. In addition, younger samples appear to have higher error rates than older samples in both of these conditions.

The two-way interaction between delay and condition was significant (see Figure 2). Across all four cue-probe conditions, the mean error rate for the short delay was significantly lower than that for the long delay. However, the difference between the short and long delay conditions in the *BX* condition was notably larger than in any of the other conditions. This is consistent with the DMC theory, which predicts that increasing the amount of time between the cue and the probe will have a stronger influence on proactive control abilities. Proactive control requires the individual to actively maintain a mental representation of cue information, which decays over time (Braver et al., 2007).

The three-way interaction among delay, condition, and sample was significant (see Figure 3). Although there was a clear main effect of delay, the relative pattern of means is approximately the same across both delays in the *AX*, *AY*, and *BY* conditions. In the *BX* condition, however, the mean error rates for the incarcerated samples are more affected by delay than the mean error rates for the control samples. It therefore appears that mental representations of cue information decay more quickly over time for incarcerated samples than for control samples.

We examined whether *AY* (measure of reactive control) and *BX* (measure of proactive control) error rates were related to participant characteristics (Tables 2 & 3). *AY* and *BX* error rates were not significantly related to each other ($r = 0.02$, $p = 0.84$). *BX* errors were significantly related to the presence of ADHD, with individuals with ADHD making more *BX* errors. To determine whether sample differences in *BX* errors could be explained by diagnosis, we simultaneously predicted *BX* errors from sample and the presence of an ADHD diagnosis. (Use of medication did not differentiate this group.) The effect of both ADHD ($F [1,141] = 4.39$, partial $\eta^2 = 0.03$, $p = 0.04$) and sample ($F [3,141] = 6.63$, partial $\eta^2 = 0.12$, $p < 0.001$) remained significant in this model. ADHD may therefore explain some (but not all) of the sample differences on proactive control between incarcerated adolescents and the other three samples.

Age was significantly related to *BX* errors, with older participants making fewer errors than younger ones. Age was also significantly related to diagnosis ($t[144] = 3.02$, $p = 0.003$), with individuals diagnosed with ADHD younger than individuals not diagnosed with ADHD. After controlling for diagnosis and sample, age had a marginally significant influence on *BX* error rates ($F[1,140] = 3.59$, partial $\eta^2 = 0.03$, $p = .06$). The effect of age on proactive cognitive control is therefore mostly due to its association with ADHD and sample. In these samples, it appears that there is less of a relation between age and proactive control when the variance attributable to sample and diagnosis is controlled.

AY errors were also significantly related to age, with older individuals making fewer errors than younger ones. However, participant ethnicity was also related to *AY* errors, with African-American participants ($M = 0.09$, $SE = 0.01$) having significantly fewer errors than Caucasian participants ($M = 0.15$, $SE = 0.01$). (Other minorities were excluded from analysis.) To determine whether sample differences in *AY* errors could be explained by ethnicity and age, we simultaneously predicted *AY* errors from sample, ethnicity, and age. The previously significant effect of sample was no longer significant in this model ($F [3,138] = 0.35$, partial $\eta^2 = 0.01$, $p = 0.79$), whereas age ($F [1,138] = 5.40$, partial $\eta^2 = 0.04$, $p = 0.02$) and ethnicity ($F [1,138] = 6.76$, partial $\eta^2 = 0.05$, $p = 0.05$) remained significant. The effect of sample on reactive control therefore appears to be due to sample differences in ethnicity and age. There does, however, appear to be effects of age and ethnicity on reactive control that cannot be explained by the effect of sample.

Discussion

This study examined the reactive and proactive cognitive control skills of incarcerated adolescents, control adolescents, incarcerated young adults, and control young adults. On a global measure of cognitive control (d' -context), incarcerated adolescents were less sensitive to context information than were to control young adults. This is consistent with previous research findings that clinical samples have reduced sensitivity to context information compared to nonclinical young adult samples (Cohen et al., 1999; MacDonald et al., 2003). Participants' sensitivity to context information decreased when the period of delay between the cue and probe increased. This finding was consistent across all four samples, replicating previous findings with different clinical and control samples (Cohen et al., 1999).

We also examined two aspects of cognitive control, reactive and proactive control. Reactive control requires that participants use context information to inhibit dominant response tendencies when determining an appropriate response. Individuals with poor reactive control make more expectancy bias errors, which are detected as false alarms in the *AY* condition on the AX-CPT. Proactive control, in contrast, requires that participants create mental representations of task relevant information when determining an appropriate response. Individuals with poor proactive control make more perceptual bias errors, which are detected as false alarms in the *BX* condition on the AX-CPT.

Participants made more errors on trials requiring cognitive control (*AY* and *BX*) than on those that did not (*AX* and *BY*). Control participants had higher error rates in the *AY* condition, whereas incarcerated participants had higher error rates in the *BX* condition. This suggests that incarcerated individuals have more difficulty implementing proactive control, whereas control individuals have more difficulty implementing reactive control. These findings are consistent with previous research showing that intact internal representations of context information (which would be expected in control samples) create invalid response expectancies in the *AY* condition. In the current study, the pattern of error rates for control participants across all four conditions on the AX-CPT was highly similar to the pattern of error rates found among healthy controls in previous studies (Barch et al., 2004; Braver et al., 2001; Braver et al., 2005; MacDonald et al., 2003). Adolescents had higher error rates in both the *AX* and *BY* conditions compared to young adults, suggesting that individuals gain both reactive and proactive abilities with development. However, the developmental trend for proactive control skills may be explained by its relation to ADHD, a point we return to.

Increasing the delay between the cue and probe caused more response errors in all four conditions, consistent with previous findings (e.g., Holmes, MacDonald, Carter, Barch, Stenger, & Cohen, 2005). Longer delays substantially increased the number of perceptual bias errors (false alarms on *BX* trials) but only slightly increased the number of expectancy bias errors (false alarms on *AY* trials). This finding is consistent with DMC theory, which predicts that increasing the amount of time between the cue and the probe will be a greater detriment to proactive control than reactive control. Proactive control requires individuals to actively maintain mental representations of context information, which decay over time (Braver et al., 2007). Reactive control does not require the active maintenance of context information. However, reactive control requires the reactivation of mental representations on an as-needed basis (Braver et al., 2007).

The three-way interaction among delay, condition, and sample was significant. Although delay clearly affected performance, the relative pattern of means found in the *AX*, *AY*, and *BY* conditions was approximately the same across both delay conditions. In the *BX* condition, however, the difference between short and long delay was larger for the incarcerated samples than for the control samples. Mental representations of cue-related information might therefore decay more quickly over time for incarcerated samples than for control samples.

We were especially interested in examining whether individual difference characteristics could explain group differences in performance. Younger samples had higher error rates in both the *AX* and *BY* conditions than older samples, suggesting that individuals gain both reactive and proactive abilities with age. However, further analyses indicated that the developmental trend for proactive control skills was due to its relation with ADHD. This finding is consistent with predictions from DMC theory that proactive control is related to disorders that are linked to impaired PFC functioning (Braver et al., 2007). Although we did not find evidence of a significant independent effect of age on proactive control skills, the possibility of natural developmental changes should be examined in future studies.

The relation between reactive control and age showed a clear developmental trend not accounted for by other variables. Older participants had better reactive control than younger ones, which may be explained by recent work on the anterior cingulate cortex (ACC). The ACC has been implicated in the ability to monitor responses, resolve conflicts in information processing, and anticipate uncertainty in outcomes (Eshel, Nelson, Blair, Pine, & Ernst, 2007; van Veen & Carter, 2002). Pathways from the ACC to a unique location in the PFC are important for engaging reactive control (Braver et al., 2007). DePisapia & Braver (2006) found that reactive control (a) was related to transient stimulation of the PFC from the ACC, (b) was required in the short-term monitoring of conflict within the ACC, and functioned to suppress task irrelevant information. The observed differences between our samples on reactive control may be explained by fMRI studies of the relation between age and the ACC, which found developmental differences in the activation of the ACC (Eshel et al., 2007; van Leijenhorst, Crone, & Bunge, 2006). To support this explanation, future research can examine whether these age effects are also found in other samples, such as those including individuals with different psychopathologies.

We also found that African-American participants had better reactive control than Caucasian participants. The relation between ethnicity and reactive control is less clear given that prior research on context processing has not examined this relation. More research on ethnicity differences in cognitive control is needed before strong conclusions can be drawn. Such research would be particularly informative for the juvenile justice system which has a number of disproportionate number of African-Americans.

Incarcerated samples had poorer proactive control than control samples. The pattern of error rates found in the incarcerated samples, where the highest number of errors occurred on *BX* trials, has also been found among individuals with disruptions in the PFC (Barch et al., 2004; Barch et al., 2004; Braver et al., 2005). Differences between groups on proactive control were partially explained by presence or absence of ADHD. This finding replicates previous research by Reeve and Schandler (2001) and Seidman, Biederman, Faraone, Weber, and Ouellette (1997), who found that individuals with ADHD have deficits in executive functions related to proactive control. These findings suggest that proactive control is impaired in individuals with diminished executive resources.

Distinguishing Proactive and Reactive Control

Error rates in the *AY* and *BX* conditions were hypothesized to provide independent estimates of reactive and proactive control skills. We confirmed this prediction, finding almost no relation between expectancy bias errors (proactive control) and perceptual bias errors (reactive control). We also found that proactive and reactive control abilities were related to individual characteristics. Perceptual bias errors, associated with failures in proactive control, were related to ADHD, whereas expectation bias errors, associated with failures in reactive control, were related to age and ethnicity. These findings provide new insights and raise questions about how reactive and proactive control may differentially relate to the use of cognitive resources, the effect of situational factors on cognitive control, and how mental health symptoms relate to cognitive control.

Braver et al. (2007) propose that proactive control engages more cognitive resources than reactive control. Proactive control requires the active maintenance of representations, using memory resources that could potentially be used for other tasks. Reactive control, in contrast, is based on directly perceived stimuli and can therefore be performed without actively maintaining representations in working memory. Braver et al. (2007) suggest that individuals with high working memory abilities are more likely to implement proactive control when necessary. They also propose that people are less likely to implement proactive control when they are under a high cognitive load. Reactive control, in contrast, is implemented more

frequently because it requires only limited cognitive resources. The dependence of proactive control on cognitive resources suggests that important individual differences in proactive control that will likely persist even following practice, training, or intervention.

Although both proactive and reactive control are used to produce goal-consistent behavior, proactive control does so using an internally maintained representation, whereas reactive control does so based on the current environmental context. This difference suggests that reactive control will likely be more influenced by irrelevant situational factors such as mood, task familiarity, and social influences than will proactive control. Results from the present study showed that older participants had better reactive control than younger participants, suggesting that deficits in reactive control should be more amenable to change through practice, training, or intervention.

Deficits in proactive control, but not reactive control, have been related to disruptions in the PFC (Braver et al, 2007), suggesting that proactive control is more closely related to individual neurobiological characteristics. Researchers have hypothesized that proactive control is disrupted in childhood disorders of executive functioning such as ADHD (Braver et al., 2007), a claim empirically supported by the present study. Individuals diagnosed with ADHD had poorer proactive control performance than those not diagnosed with ADHD, independent of the effects of age. Previous studies found similar results, indicating that individuals with ADHD have deficits in executive functions analogous to proactive control (Barkley et al., 2001; Reeve & Schandler, 2001; Seidman et al., 1997; Strandburg, Marsh, Brown, Asarnow, Harper, & Guthrie, 1996). The current study additionally found that reactive control was not related to the presence of an ADHD diagnosis. Future research should further examine the reactive and proactive control abilities of individuals with different psychological diagnoses.

Cognitive Control and Delinquency in Adolescence

Researchers have argued that criminal culpability should be mitigated by the developmental immaturity of adolescents (Scott & Steinberg, 2003; Steinberg & Cauffman, 2001; Steinberg & Scott, 2003). Susceptibility to environmental influence is likely affected by proactive control, which reflects the ability to adhere to internal principles in the face of conflicting environmental demands. Decision-making skills are likely influenced by both reactive and proactive control since good decisions selectively make use of both the individual's internal principles and the features of the situation. We found that reactive control skills were related to age, consistent with common beliefs about the development of maturity through adolescence. Measures of reactive and proactive control may be useful to assess cognitive maturity as a supplement to other commonly used measures.

Findings from the current study also indicate the importance of evaluating individual differences beyond age in making legal decisions regarding juveniles. In particular, ADHD influenced proactive cognitive control skills and may indirectly influence criminal culpability. Investigations of the relation between mental health disorders and cognitive control could provide important empirical evidence relevant to juvenile justice policy. Such examinations are particularly important given research findings that incarcerated adolescents have high prevalence of mental health disorders (Teplin, Abram, McClelland, Dulcan, & Mericle, 2002; Wasserman, McReynolds, Lucas, Fisher, & Santos, 2002). Specific mental health disorders and symptoms are likely differentially related to proactive and reactive control. Research that clarifies such relations would be valuable to prevention and intervention efforts with delinquent adolescents, pinpointing optimal and developmentally appropriate treatment targets. Interventions and training that facilitate ability to appropriately reconcile conflicting contextual information in the immediate decision-making situation might be effective in enhancing cognitive control. Developmental changes in adolescence may naturally facilitate the growth of such skills; however, for delinquent youth, cognitive interventions may be

necessary. Interventions that provide training and that reduces the speed at which mental representations decay would be especially important.

Limitations and Future Directions

Findings from the current study highlight areas in need of future research. We did not include direct measures of brain activity. fMRI techniques would provide more direct and powerful measures of how cognitive control skills differentially relate to brain activity. Additionally, we only examined males, and it is unclear whether our results would generalize to females. It would be fruitful to examine possible gender differences in cognitive control skills, particularly with regard to female offenders. Finally, longitudinal investigations are necessary to understand fully how cognitive control skills develop with age. It would be particularly interesting to compare the developmental trajectories of typically developing adolescents to those of delinquent adolescents. Also, more accurate measures of ADHD than the self-report used in the present work could provide stronger evidence for the relation between proactive control and this disorder.

In conclusion, findings from the current study provide support for examining cognitive control as involving two mechanisms, reactive and proactive control. These abilities represent distinct cognitive skills that are differentially related to individual characteristics such as diagnosis and age. In addition to these findings providing further empirical support for the DMC model proposed by Braver and colleagues (2007), our findings also add to the rapidly growing base of evidence suggesting that more complex cognitive skills may not be fully developed in adolescents.

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Figure 1.
Interaction between condition and sample.

Figure 2.
Interaction between condition and delay.

Figure 3.
Interaction Among Delay, Condition, and Sample.

Table 1

ANOVA model predicting arcsine transformed error rates.

Effect	Test Statistic	p-value	partial η^2	Wilks' Lambda
Delay	$F(1,143) = 185.74$	<0.001	0.57	0.44
Condition	$F(3, 141) = 232.06$	<0.001	0.83	0.17
Sample	$F(3, 143) = 5.30$	0.002	0.10	–
Delay * Condition	$F(3,141) = 47.11$	<0.001	0.50	0.50
Sample * Condition	$F(9,343) = 4.25$	<0.001	0.08	0.77
Delay * Sample	$F(3,143) = 0.72$	0.54	0.02	0.99
Delay * Condition * Sample	$F(9,343) = 2.33$	0.02	0.05	0.87

Note: – = not calculated for between-subjects effects

Table 2

Sample Demographic Statistics.

Variable	Control Adolescents (n=33)	Control Young Adults (n=31)	Incarcerated Adolescents (n=43)	Incarcerated Young Adults (n=40)
Age				
Mean	14.52 ^a	19.34 ^b	15.70 ^c	20.86 ^d
Standard Deviation	1.53	0.80	1.67	1.47
Range	(12.08, 17.56)	(18.22, 21.15)	(12.24, 18.60)	(18.09, 23.01)
Race/Ethnicity				
White	61% (n=21)	84% (n=26)	35% (n=15)	27% (n=11)
Black	36% (n=12)	10% (n=3)	65% (n=28)	73% (n=29)
Hispanic	0% (n=0)	3% (n=1)	0% (n=0)	0% (n=0)
Multiple Races	3% (n=1)	3% (n=1)	0% (n=0)	0% (n=0)
SES				
Mean	3.56 ^a	4.42 ^c	3.04 ^b	2.90 ^b
Standard Deviation	0.72	0.66	0.70	0.91
Range	(2, 5)	(3, 5)	(2, 4)	(1, 5)
K-BIT 2 Composite				
Mean	94.45 ^{ab}	100.58 ^b	86.40 ^{ac}	82.00 ^c
Standard Deviation	11.67	16.48	12.46	9.08
Range	(72, 118)	(64, 132)	(64, 121)	(55, 103)
DRUG & ALCOHOL (CSAP)				
Mean	–	5.35 ^a	7.09 ^a	10.63 ^b
Standard Deviation	–	4.13	4.55	3.52
Range	–	(0, 13)	(0, 14)	(0, 16)
NUMBER OF HEAD TRAUMAS				
Mean	0.27 ^a	0.32 ^{ab}	0.67 ^{ab}	0.85 ^b
Standard Deviation	0.45	0.48	0.93	1.12
Range	(0, 1)	(0, 1)	(0, 5)	(0, 4)

SES = Socio-Economic Status; K-BIT 2 = Kaufman Brief Intelligence Test-Second Edition; Within a row, means that share a superscript are not significantly different from each other ($\alpha = 0.05$).

Table 3

Relations between AX-CPT errors and individual difference variables.

<i>Zero-Order Correlations</i>			
		<i>AX-CPT Measure</i>	
		<i>BX Errors^a</i> (Proactive Control)	<i>AY Errors^a</i> (Reactive Control)
Age		-0.24 ^{**}	-0.28 ^{**}
K-BIT 2 Composite IQ		-0.14	0.06
Drug & Alcohol Use (CSAP) ^b		-0.11	-0.04
Number of Head Traumas		-0.04	-0.11
Socio-Economic Status		-0.09	0.06
<i>ANOVAs</i>			
		<i>AX-CPT Measure</i>	
		<i>BXErrors^a</i> (Proactive Control)	<i>AYErrors^a</i> (Reactive Control)
Ethnicity ^c	F-value (df)	3.82 (1, 142)	9.32 (1, 142) ^{**}
Diagnosis	F-value (df)	8.55 (1, 144) ^{**}	0.61 (1, 144)

Note: * $p \leq 0.05$,

**
 $p \leq 0.01$

^a averaged across short and long delay conditions because the correlations did not significantly differ from each other based on delay (a table of these correlations and tests of their differences is available from the first author)

^b data collected only from detained youth, community young adults, and young adult prisoners

^c there were not enough participants of Hispanic or multiple ethnicities to statistically examine, so this variable compares White and Black participants only; K-BIT 2 = Kaufman Brief Intelligence Test-Second Edition; CSAP = Center for Substance Abuse Prevention Youth Survey; Diagnosis = compares individuals diagnosed with ADHD to those not diagnosed with ADHD.