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Context Processing Abilities in Chronic Cocaine Users

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Abstract

Cocaine dependence is a particularly severe problem in the United States, resulting in broad economic and personal costs. Significant evidence of generalized cognitive deficits associated with cocaine dependence has been reported. Two studies evaluated whether context processing, the processes involved in representing and maintaining information regarding the context of one's environment, might be seen as a process-specific deficit that may explain some aspects of the broader cognitive deficits associated with cocaine dependence. Study 1 used the expectancy variant of the AX task to assess this ability; Study 2 employed the Dot Pattern Expectancy (DPX) task. Significant between-group differences were found in each study for d'-context, a comparison of AX hits and BX misses; these results indicated significant between-group differences in context processing ability. In Study 1, significant between-group a priori contrasts of AY vs. BX trials indicated the likelihood of a specific deficit in context processing in the cocaine group; however, this contrast was not significant in Study 2. Overall, the results of these studies support the theory of impaired context processing ability associated with cocaine misuse. However, these results do not allow for the interpretation of a process-specific deficit in context processing ability. Future research targeted at investigating aspects of this context processing impairment associated with cocaine misuse can shed light on the specificity of this deficit.

Keywords

cocaine; drug dependence; cognitive control; executive functioning

Cognitive deficits among individuals who have become dependent on recreational drugs can provide insight into both the mental processes associated with the etiology of addiction, as well as the long-term effects of substance use on the brain. Cocaine is a particularly potent recreational drug, with an estimated risk of developing dependence once use has started of 5–6% (O'Brien, 2005). Risk of developing dependence is increased greatly for certain demographic groups (females, African-Americans, and young adults, (Kandel, Chen, Warner, Kessler, & Grant, 1997)), as well as certain methods of use (crack cocaine and intravenous drug injection). Additionally, the effect of overall cocaine use on society is substantial, with an estimated annual cost of approximately 180.9 billion dollars (Policy, 2004). Various aspects of cognitive functioning have been found to be impaired in individuals who are dependent on cocaine, including working memory, decision making, and cognitive flexibility (van der Plas, 2009), leading researchers to conclude that at least a

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mild degree of generalized cognitive impairment is associated with this disorder (Goldstein, 2004).

One class of tasks on which cocaine dependent patients have often been found to be impaired are those tasks that require control from higher-level cognitive processes over automatic responses triggered by bottom-up perceptual and encoding processes. An example of this would be using higher-order control to overrule automatic responding when asked to ignore the content of a word and instead focus on other aspects, such as the color in which it is displayed (Cohen, Dunbar, & McClelland, 1990; Stroop, 1935). This type of higher order control is often referred to as top-down executive control. Various aspects of top-down executive control have been found to be impacted by cocaine use in numerous studies (Hester & Garavan, 2004; Rosselli, 2001; Verdejo-Garcia & Bechara, 2006). For example, Hester and colleagues found decreased inhibitory abilities in cocaine users on performance of a Go-No Go task (Hester & Garavan, 2004). Additionally, cocaine users in that study displayed decreased activity in the right prefrontal and anterior cingulate cortices, compared to healthy controls; these areas have been found to be associated with cognitive control abilities. Similar behavioral results have been found with the stop signal task (Fillmore & Rush, 2002). Additional research identified decreased activity in the rostral anterior cingulate cortex in cocaine dependent individuals associated with poorer inhibitory performance on the stop signal task (Li, et al., 2007). Cocaine use has also been associated with markers of increased impulsivity, particularly on tasks that investigate how one assesses the value of immediate and delayed rewards. Both rodent and human models have found cocaine use to be linked with decreased valuing of delayed rewards (Coffey, Gudleski, Saladin, & Brady, 2003; Dandy & Gatch, 2009). Significant relationships have been reported between the severity of cocaine abuse and the level of impairment in inhibition, as measured by interference on the Stroop task (Verdejo-Garcia, Lopez-Torreclillas, Aguilar de Arcos, & Perez-Garcia, 2005) and the stop signal task (Colzato, van den Wildenberg, & Hommel, 2007), and executive functioning, as measured by performance on the Trail Making Test, part B (Spree & Strauss, 1998), and the Wisconsin Card Sort Task (WCST) (Bolla, Rothman, & Cadet, 1999; Stuss & Levine, 2002). Although a generalized deficit cannot be ruled out as the source of these deficits, they do suggest that a failure of top-down control would be a reasonable domain in which to look for a specific deficit.

An integral aspect of top-down control is context processing. Context processing is a delineated construct that refers to the representation and maintenance of information regarding the current or recent context of one's environment. The specific role of context processing in cognition was initially described by Cohen and colleagues, who proposed a theory of a specific deficit in context processing in patients with schizophrenia (Cohen & Servan-Schreiber, 1992a). Cohen and colleagues posited that an underlying deficit in context processing ability might contribute to overall poorer executive functioning performance in individuals with schizophrenia. Given that information from one's context is often integral in guiding behavior, it is likely that the mechanism of representing contextual information plays an important role in numerous tasks and cognitive processes, such as decision making. When completing an experimental cognitive task, one must first represent and then maintain the contextual information (i.e. rules governing responses) to be successful. For example, the rule of "say the color of the ink in which the word is printed" in the Stroop task is contextual information. To override one's habitual response to read the text of words, one must maintain this rule of one's contextual environment to guide the response. Thus, the mechanism of maintaining contextual information is needed to complete this task. Context processing deficits have also been investigated in numerous populations experiencing generalized cognitive impairment, including older individuals (Braver & Barch, 2002; West,

2004) and individuals with traumatic brain injuries (Larson, Perlstein, Demery, & Stigge-Kaufman, 2006).

Similarly, while much research has documented mild impairments in top-down control associated with cocaine abuse, it is possible that a core deficit in context processing ability is underlying these observed impairments across a wide variety of tasks. For example, to perform successfully on a Go-No Go task, one must process and maintain the contextual information of the task (i.e., task instructions, information delineated by stimulus characteristics, expected relationships between stimuli and responses). Thus, while tasks that measure context processing do not directly target response inhibition per se, these tasks measure a specific cognitive process that plays a role in successfully inhibiting responses, and activation patterns measured using fMRI show a great deal of overlap in brain activation patterns (Niendam, et al., 2012). While the relationship between context processing, inhibition and impulsivity appears to be potentially significant, context processing ability has yet to be investigated in individuals who have abused cocaine. These studies offer an initial investigation of this cognitive process associated with cocaine misuse.

Specific deficits can be divided into two categories: (1) deficits that are known to occur in a certain disorder and can be used to differentiate the presence of one disorder from another; these are often referred to as diagnostically-specific deficits; and (2) deficits that occur in specific cognitive processes that may contribute to the presence of generalized cognitive deficits; these are often called process-specific deficits. While an understanding of generalized executive functioning impairment is helpful in the conceptualization of cocaine dependence, research has focused on the additional utility of process-specific deficits in various forms of psychopathology (Chapman & Chapman, 1973; MacDonald & Carter, 2002; Strauss, 2001). By targeting specific cognitive processes, researchers are able to investigate aspects of cognition that are mechanistically interpretable and have real-world consequences. For example, by assessing a process-specific deficit of short-term memory, individuals can develop coping strategies to deal with the impairment of this process-specific deficit on their daily lives. Investigating potential process-specific deficits offers the opportunity to assess specific cognitive processes that may either be involved in the development of cocaine dependence and/or be associated with the effects of chronic cocaine use on the brain. Thus, investigating context processing ability in individuals with cocaine abuse or dependence offers the opportunity to assess (1) whether a core deficit in context processing ability is present and may underlie or be contributing to the mild cognitive impairment commonly associated with these disorders, and (2) whether this deficit is a process-specific deficit, which would likely play a significant role in the development and/or maintenance of these disorders.

Study 1

The primary goal of Study 1 was to use a context processing task, the expectancy variant of the AX task (MacDonald, 2008; Servan-Schreiber, Cohen, & Steingard, 1996), a modified version of the original AX Continuous Performance Task (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956), to examine possible deficits in context processing in those diagnosed with cocaine dependence. Based on past research suggesting deficits in response inhibition in individuals dependent on cocaine and the possibility these deficits may be associated with impaired context processing, we hypothesized those dependent on cocaine would display slower and less accurate responding on the AX task, relative to the control group. The expectancy AX task uses comparisons of stimuli that tax context processing ability at differing rates. Slower and less accurate performance on certain trial types is indicative of poorer context processing ability. The between-group differences in speed and accuracy were hypothesized to be greatest on trials that tax context processing ability over-

and-above more general cognitive skills (Cohen, Barch, Carter, & Servan-Schreiber, 1999; Cohen & Servan-Schreiber, 1992b; Servan-Schreiber, et al., 1996).

Methods

Participants—Participants for this study were recruited through free local-area and university campus publications, and flyers on community bulletin boards. Subject recruitment materials did not target specific demographic groups, although they were specific to the sample being recruited. The style and content of recruitment materials were similar for control and cocaine dependent samples. The consent procedures and experimental design were reviewed and approved by the University of Minnesota institutional review board (IRB) before the study began (Lim, et al., 2008). All participants gave written informed consent and HIPAA consent to participate in the study. The Structured Clinical Interview for DSM-IV, Axis I (SCID-I) (First, Spitzer, Gibbon, & Williams, 1995) was used to assess clinical diagnosis. Cocaine dependent participants were given the patient version of the SCID to screen for all Axis-I disorders, while control participants were assessed using the non-patient version. Cocaine dependent participants all met DSM-IV criteria for cocaine dependence within the last 30 days and were abstinent from cocaine for at least four days prior to testing. All cocaine dependent participants had been using cocaine for at least six months and had used cocaine at least six times in the last month. Urine analysis was used in conjunction with self-report to confirm use of cocaine in the cocaine participants, whereas only self-report was used to measure current abstinence. The use of other substances was also monitored through urine analysis. Control subjects were excluded from participation if they reported a history of any substance dependence or excessive use of alcohol (i.e. more than 14 drinks per week for men and more than 10 for women) was present. Urine analysis was not completed for control participants. Exclusion criteria for all participants included any brain disease, including past concussions; current use of psychotropic medications; or history of any neurological or psychiatric disorders other than cocaine or alcohol dependence. Two participants were diagnosed with both alcohol and cocaine dependence. Eight cocaine dependent participants were also diagnosed with HIV, which was therefore used as a covariate. As part of their initial assessment, participants completed the Barratt Impulsiveness Scale (BIS) (Patton, Stanford, & Barratt, 1995). The total score for the BIS was calculated by summing all 30 items. This scale was included to measure the presence and degree of impulsive personality traits in all participants. Additional details on participant recruitment and selection are available in (Lim, et al., 2008).

Seventy participants, ages 18 to 53, completed this study. Nine participants were later removed from the study because of partial missing data, and three were removed because of error rates greater than .90 on the AX task. Thus, 58 participants were included in the analyses described in this paper: 34 cocaine dependent participants and 24 control participants. Cocaine dependent participants had a mean of 18.9 years of use and a range of 3 to 28 years. A profile of the participants is displayed in Table 1, with standard deviations given in parentheses. Analyses indicated control participants were well-matched with cocaine dependent individuals for age and sex. Significant differences in years of education and race distribution between groups were found.

Task Procedure—Testing took place on the campus of the University of Minnesota. Participants completed the expectancy version of the AX-CPT. Participants were instructed to fixate on the center of the screen for the duration of the task and to respond to each letter presented. The task was introduced to participants using a visual aid, as well as on-screen and verbal instructions. Participants then completed practice trials until the task was understood. Trials consisted of a cue and a probe pair that were presented separately for

1000ms. To eliminate extraneous factors affecting the validity of this measure, there was a 3,000 ms delay between the presentation of the cue and probe, requiring the participant to maintain the cue over the delay to correctly classify the probe. Stimuli were letters from the English alphabet. Each letter presented was classified by the experimenter as A, B, X, or Y: cues that were any letter other than A were classified as a B and probes that were any letter other than X were classified as a Y. Participants responded using a button press classifying probes as 'target' or 'non-target.' Participants were instructed to respond 'target' only to an X probe that was preceded by an A cue. To all other letter sequences, the participant was instructed to respond 'non-target'. For example, if an X probe was preceded by a B cue, the correct response for the X would be 'non-target'; likewise, if a Y probe follows an A cue, the correct response for the Y would be 'non-target'. Trials were presented in a randomized order of the four letter sequences (AX, AY, BX, BY).

The expectancy AX task has been modified to include the largest proportion of trials as AX (77%), with the remaining 23% of trials divided between AY, BX, and BY; this resulted in 260 AX trials, 30 AY trials, 30 BX trials and 16 BY trials. The relatively large proportion of AX trials was designed to create the expectancies that (1) an X probe would follow an A cue and (2) an X probe would most likely be a 'target'. These expectancies led to having to overcome the prepared response of pressing the 'target' button for an X probe and for any probe that follows an A; thus, the participant would need to overcome this prepared response when viewing AY or BX trials.

Statistical Analysis—Raw error rates were calculated as the percentage of incorrect responses out of total responses and were normalized using an arcsine transformation on the square roots of the error rates prior to analysis. D -context (Servan-Schreiber, et al., 1996) was also used to measure the pattern of response accuracy across trial type. This statistic was calculated by subtracting the z-transformed probability of false alarms on BX trials from the z-transformed probability of correct hits on AX trials. Participants with 100% accuracy were replaced with the equivalent of responding incorrectly to one trial. An independent samples t-test was used to analyze the difference in d -context between groups. Differences in error rates and response times were evaluated using a mixed effects repeated measures ANOVA with trial type as a 4-level within group variable (trial type: AX, AY, BX, BY) and substance diagnosis (diagnosis: cocaine dependent or control) as a between group variable and HIV status as a binary-variable covariate. Planned contrasts investigated differences in error rates and response times between the two groups on AY and BX trials. Effect sizes were calculated using partial eta squared statistics. Correlational analyses were completed to investigate the relationship between impulsive personality traits, as measured by the BIS, and context processing performance, as measured by d -context.

Results and Discussion

Between-group effects were examined, and a significant difference in d -context was found between the groups ($t(53)=2.82$, $p=.007$, $r=.36$), with the control participants' mean being significantly higher than cocaine dependent participants. This significant difference indicated that the control participants were more sensitive to the context of an A or B cue than cocaine dependent participants. However, since the measure of d -context may be affected by differences in generalized performance, this measure is not the most sensitive to the presence of a specific deficit in context processing.

To target the presence of a specific deficit, a priori contrasts were run on the differences between AY and BX trial types between groups for accuracy and response time. The planned contrast of AY vs. BX errors indicated the cocaine dependent participants made significantly more BX errors than controls, while the two groups made a similar number of

errors on AY trials ($F(56, 1)=9.319, p=.003, \eta^2=.0143$). Similarly, the planned contrast of AY vs. BX response times was also significant ($F(56, 1)=4.202, p=.045, \eta^2=.0070$), with the between-groups difference in response time being greater for BX trials than AY trials. These contrasts continued to be significant with HIV status entered as a covariate. Together, these a priori analyses that specifically contrast performance on AY vs. BX trial types support the theory of a process-specific deficit in context processing in cocaine dependence by indicating that the difference between groups was greatest on trials that most taxed context processing ability (BX trials), and more similar on other trials of a similar levels of difficulty (AY trials). Additionally, this contrast suggests that the cocaine dependent participants' deficits in performance, relative to the control group, are primarily related to context processing deficits, rather than poor effort.

In addition to a priori contrasts, main effect and overall trial type x group interactions were also assessed to gain an understanding of the overall pattern of performance between groups. With HIV status as a covariate, a main effect of trial type was found for error rates ($F(165,3)=33.452, p<.001, \eta^2=.378$), as well as a marginal main effect of group ($F(55,1)=3.82, p=0.056, \eta^2=.065$). While cocaine dependent participants made marginally significantly more errors than control participants across trial types, the BX trial type was associated with more errors in both groups. The trial type x group interaction was not significant ($F(165,3)=.173, p=.914, \eta^2=.003$). The mean error rates by trial type and group are displayed in Figure 1b; standard error bars are shown. For response time, there was a main effect of trial type ($F(165,3)=38.756, p<.001, \eta^2=.413$), with both groups having the slowest response times for AY trials. A marginally significant main effect of group was also found ($F(55, 1)=3.875, p=0.054, \eta^2=.066$), with the cocaine dependent participants having marginally slower response times across trial types. The trial type x group interaction was not significant.

Among cocaine dependent participants, we observed a moderate relationship in the hypothesized direction between impulsivity, as measured by the Barratt Impulsiveness Scale, and d -context ($r=-.29, p_{1-tailed}=.047$). This indicated that as levels of impulsivity increased, level of context processing ability tended to decrease.

In Study 1, measures of context processing, including d -context and a priori contrasts of AY vs. BX trials, indicated a significant difference in context processing ability between cocaine dependent participants and control participants. Additionally, in the cocaine dependent participant group, a marginally significant relationship between impulsivity and context processing ability was found. While these results suggest the presence of a context processing deficit in individuals with cocaine dependence, there were also significant limitations to this sample. Particularly, the participant groups differed on demographic variables, such as race and years of education, and the potential contribution of these variables could not be fully controlled using statistical procedures. To address the possibility that the between-group differences in context processing were significantly related to between-groups demographic differences, a second study was undertaken using a variant of the expectancy AX task used in Study 1 using more comparable control participants.

Study 2

To address the limitations of Study 1, we conducted a follow-up study investigating context processing in two groups that were well-matched on several demographic variables using a variant of the expectancy AX task that required participants to represent and maintain the context evoked by a visuospatial stimulus, the Dot Pattern Expectancy (DPX) task. This task was included to investigate the presence of context processing deficits across different methods of stimuli characteristics and task environment. The DPX task builds upon the

expectancy AX task created by Cohen and colleagues (Servan-Schreiber, et al., 1996). In this variant of the expectancy AX task, simple dot patterns were used for all stimuli rather than letters. Because the DPX task uses dot patterns that are much less salient to participants than English letters, the duration of the delay between cue and probe stimuli is able to be much shorter, thus increasing the efficiency of this task.

The DPX task has been validated in several samples as an acceptable measure of this construct (Jones, Sponheim, & MacDonald, 2010). Study 2 sought to investigate the presence of a significant deficit of context processing in individuals dependent upon cocaine. In this study, groups were well-matched for demographic variables; thus, any significant group differences that may arise can be more clearly attributed to cognitive differences between groups presumably associated with substance use. Given the findings of Study 1, we hypothesized that significant main effects of trial type and group would be found. We also hypothesized that measures used in Study 1 (d -context, a priori contrasts of AY vs. BX trials) would indicate significant group differences in context processing ability.

Methods

Participants—Participant recruitment, consent and screening procedures closely followed those conducted in Study 1. This study was conducted as a portion of a larger study investigating the relationship between cocaine dependence and a number of additional mechanisms besides context processing, such as GABA neuron density as measured using MR spectroscopy. Each participant was screened using an appropriate version of the SCID-I (First et al., 2002). Cocaine dependent participants met DSM-IV criteria for cocaine dependence throughout the past year and had been using cocaine for at least one year. Exclusion criteria for all participants included any brain disease, use of psychotropic medications, or history of any neurological disorders; participants may have had previous diagnoses of dependence on other substances in the past, but currently only met criteria for cocaine dependence. Similar to Study 1, all participants completed the Barratt Impulsiveness Scale as part of their initial assessment.

Seventy participants, ages 19 to 46, completed this study. Two participants were later removed from the study because of partial missing data, and six were removed because of error rates greater than .90 on the DPX task. Thus, 62 participants were included in the analyses described in this paper: 31 cocaine dependent participants and 31 control participants. Cocaine dependent participants had a mean of 15.3 years of use and a range of 2 to 25 years. A profile of the participants is displayed in Table 1, with standard deviations given in parentheses. Analyses indicated control participants were well-matched with cocaine dependent individuals for age, sex, and race. However, there was a significant difference in years of education ($t(60)=-5.13, p<.001$), with the cocaine group having significantly fewer years of education than the control group.

Task Procedure—Testing was completed on the campus of the University of Minnesota. Whenever references are made to certain trial types for the DPX task, e.g. AX, this is referring to the dot patterns that were assigned to each Latin letter; these assignments were consistent throughout the tasks. Task trials were presented in a randomized order of the four letter sequences (AX, AY, BX, BY). The cue and probe dot pattern stimuli were presented each for 1000 ms. To further eliminate extraneous factors affecting the validity of this measure, there was a 3,000 ms delay between the presentation of the cue and probe, requiring the participant to maintain the cue over the delay to correctly classify the probe. During the task, participants are instructed to press the ‘target’ button when an X was presented that had been preceded by an A; for every other stimulus, they were to press the ‘non-target’ button. For example, if an X probe was preceded by a B cue, the correct

response for the X would be 'non-target'; likewise, if a Y probe follows an A cue, the correct response for the Y would be 'non-target'. The task was introduced to participants using an on-screen visual aid, as well as on-screen and verbal instructions. Participants then completed practice trials until the experimenter felt the task was well understood. After practice, participants completed two blocks of the task, with each block containing 33 AX trials, 6 AY trials, 6 BX trials and 3 BY trials.

Similar to the AX task, the DPX task includes the largest proportion of trials as AX (69%) with the remaining 31% of trials divided between AY, BX, and BY; this resulted in 66 AX trials, 12 AY trials, 12 BX trials and 6 BY trials

Statistical procedures for study 2 closely followed those described for study 1.

Results & Discussion

Between-group effects were initially examined. A between-groups significant difference in d -context was found ($t(60)=-2.28$, $p=.026$); mean d -context was significantly higher for control participants than for cocaine dependent participants (Figure 1c), indicating greater sensitivity to context for control, compared to the cocaine dependent, participants.

As in Study 1, a priori contrasts of accuracy of performance and response time on AY vs. BX trial types were conducted to assess the presence and strength of a specific deficit in context processing. The planned contrast of error rates for AY and BX trials documented that, unlike Study 1, there was not a significant difference between performance accuracy of the two groups of participants on these trial types ($p>.7$, Figure 1d). However, this effect was closer to significance when educational attainment was entered as a covariate ($F(2.8, 58)=2.8$, $p=.10$). Planned contrast of between-group differences of response times on AY and BX trials was also not significant ($p>.9$). In addition to planned contrasts, we examined the overall trial type x group interaction. A main effect of trial type was found to errors ($F(180,3)=18.7$, $p<.001$, $\eta^2=.238$). A marginal main effect of group was found for errors ($F(60, 1)=3.005$, $p=.088$, $\eta^2=.048$). Similar to Study 1, the greatest proportion of errors occurred on BX trials. The cocaine dependent participants tended to make more errors overall than control participants, although this difference was only marginally significant. The trial type x group interaction for error rates did not approach significance ($p>.35$). Mean error rates by trial type and group are displayed in Figure 1d; standard error bars are shown.

A significant main effect of trial type was also found for response time ($F(180,3)=28.871$, $p<.001$, $\eta^2=.317$). There was also a significant main effect of group for response time ($F(60, 1)=7.122$, $p=.010$, $\eta^2=.106$). Both groups made the slowest responses for AY trials. The cocaine dependent group tended to make slower responses than control participants across all trial types. Thus, the trial type x group interaction for response time was not significant ($p>.75$).

Within-group effects were also analyzed. In the sample of cocaine dependent participants, a significant relationship between a measure of impulsivity (BIS) and context processing ability (as measured by d -context) was not found ($r=.035$, $p=.87$). For cocaine dependent participants, years of cocaine use was not significantly related to context processing ability ($r=-.037$, $p=.88$). Thus, a number of aspects of Study 2 failed to confirm the results of Study 1.

General Discussion

These studies were designed to investigate the potential presence of a specific deficit in context processing ability associated with cocaine dependence. In Study 1, there was a significant difference between groups on d -context, a measure which contrasts correct

responses on AX trials with incorrect responses on BX trials. This initial indicator of a between-groups difference in context processing ability was supported by significant a priori contrast of AY vs. BX trials for both accuracy and response time. This contrast revealed that the cocaine dependent participants performed significantly worse than controls on BX trials, while the difference between groups' performance on AY trials was much smaller. Additionally, a significant relationship between context processing ability and impulsivity personality traits was found in the cocaine dependent sample. In Study 2, samples that were better-matched for race were studied using a newer context processing task, the DPX task. This task was employed as a more efficient measure of context processing than the expectancy-AX task used in Study 1. Similar to Study 1, a significant difference between groups was found on d -context in Study 2, indicating a significant difference in context processing ability between groups. However, unlike Study 1, the a priori contrast of AY vs. BX trials was not significant. As well, the relationship between context processing performance and impulsivity was not significant in the cocaine sample.

Further analysis of the results of Study 1 and 2 sheds light on the potentially discordant conclusions of these two studies. For both Study 1 and Study 2, the effect size of the between-groups difference on d -context was moderate. Conversely, the effect size of the a priori AY vs. BX contrast was moderate in Study 1, but was of much smaller magnitude in Study 2. This between-study difference in AY vs. BX effect size highlights the possibility that the presence of a specific deficit in context processing ability was interpretable in Study 1, but was not interpretable in Study 2. In theory, a specific deficit in context processing ability is indicated by control participants demonstrating particular difficulty on AY trials, which are designed to be the most difficult trial type. Conversely, individuals with poor context processing tend to display the greatest difficulty on BX trials, while control participants display greater accuracy on this trial type than on AY trials (Jones, et al., 2010). Relatively poorer accuracy on AY trials in controls was not observed in either Study 1 or Study 2. Rather, in each study, both the cocaine dependent and the control participant groups displayed the greatest difficulty on BX trials. The significant between-groups differences found for d -context in each study likely indicates that, in both studies, cocaine dependent individuals displayed poorer context processing ability. However, the pattern of performance of controls also having the greatest amount of errors on BX trials precluded the presence of a specific deficit in context processing ability being interpreted

Similar difficulty in consistently interpreting process-specific deficits associated with cocaine misuse has occurred in numerous studies. Initial research into specific cognitive impairments found no significant impairments in individuals who have abused cocaine (Selby & Azrin, 1998). However, further research found that the development of cognitive impairments was significantly related to amount of cocaine use (Bolla, et al., 1999). These results highlighted the importance of considering amount and duration of use when studying the cognitive impact of substance abuse. As neither of the studies included in this paper measured amount and duration of cocaine use, it is possible that differences in these group characteristics may be precluding clear interpretation of a specific deficit of context processing associated with cocaine use. The likelihood of this possibility may be increased by the discordant findings regarding context processing performance and impulsive personality traits, as amount and duration of cocaine use may be impacted by the severity of impulsive personality traits.

Additional research aimed at identifying process-specific cognitive impairments associated with cocaine abuse has been inconclusive. Various studies have indicated that deficits in the areas of working memory, trial-by-trial verbal learning, and measures of executive functioning, such as overall errors on the WCST and time to complete the color-word test of the Stroop Neurological Screening Test, are associated with cocaine abuse (Rosselli, 2001).

However, a quantitative review of numerous studies investigating neuropsychological performance associated with cocaine abuse found deficits in the areas of working memory and some aspects of executive functioning (Stroop task interference score, Porteus Maze performance), but did not find impairment on other measures of executive functioning, as all measures on the WCST were not significantly different in cocaine groups vs. control groups across studies reviewed (Jovanovski, Erb, & Zakzanis, 2005).

Given the overall literature support for a generalized cognitive impairment associated with cocaine abuse, it is not surprising that the cocaine samples in both Study 1 and Study 2 performed more poorly overall than the control samples. Additionally, the difficulty in interpreting a specific deficit or aspect of executive functioning does not appear to be unique to these studies. Rather, numerous research studies described above have found evidence of impairment in certain aspects of executive functioning, but not in others. The results of Studies 1 and 2 do not rule out the possibility of a specific deficit in context processing; rather, task performance in these studies was not clear enough to allow the presence of a process-specific deficit to be interpreted. However, while the results cannot be unambiguously interpreted, they remain consistent with a context processing impairment among cocaine users. This suggests the possibility that a core deficit in context processing either underlies or contributes to the well-documented impairments in top-down control that are commonly associated with cocaine abuse or dependence.

Limitations

As noted, Study 1 showed significant differences in race and years of education between the cocaine dependent and control participant groups; these significant demographic differences limit the ability to interpret any between-group differences as being associated with cocaine dependence rather than demographic differences. Additionally, eight of the cocaine dependent participants in Study 1 were diagnosed with HIV, a condition that may have impacted the cognitive performance of those participants. Study 2 was designed to continue investigating context processing ability associated with cocaine dependence in groups that were well-matched for demographic variables. As might be expected with a disorder that affects educational attainment (Meehl, 1970), there was a significant difference in years of education between the two participant groups. As Meehl discussed, the logic of matching for variables such as years of education can lead to misleading results and other confounds (Meehl, 1971), and therefore the role of education as a suppressor variable is somewhat surprising. In Study 2, no significant differences in parental educational attainment were found. This measure may be a more valid index of intellectual aspiration while, as noted above, participants' educational attainment is often affected by the presence of any mental disorder.

Another limitation falls in the area of assessment regarding reported alcohol and other drug use by study participants. In this study the use of interview and other self-report measures of substance use, with no physiological confirmations of severity of cocaine use, as well as no rule-outs of use of any other substance, including alcohol, leaves the possibility that use of alcohol or other substances may contribute to impairments in the cocaine groups. Additionally, while all cocaine dependent participants identified cocaine as their primary dependent substance, the nature of this disorder involves these participants being more likely to have used other substances than the control participants. Likely variance in the quality cocaine and additional substances used, both within and across subjects, is also a potential limitation in studies of this nature. Dependence on any other substance was an exclusionary criterion for study participation, with the exception of alcohol dependence in Study 1. This reduced the impact of polydrug use on the study's findings, but does not rule-out possible effects of previous exposure to multiple substances.

The study design also precluded the possibility of disassociating the etiological importance of context processing failures in cocaine dependence – that is the case-control comparison conflated the effects of cocaine with any predisposing effects to cocaine dependence. Finally, as with any negative findings, there are concerns about power. The study was adequately powered to demonstrate the generalized deficits associated with cocaine dependence, as evidenced by significant between-group differences in d -context in both studies. Therefore, a specific deficit in context processing over-and-above this generalized deficit measured in Study 2 must certainly have had a smaller effect size, below our threshold of sensitivity; a sensitivity analysis indicated that with a total sample of 62, $d = .05$, and $d = .80$, our threshold for sensitivity was an effect size of $.25$. A priori contrasts of AY vs. BX trials for both studies yielded effect sizes below this threshold. The limitation of small sample size was inherent to the procedures selected, as Study 2 was conducted as a portion of a larger study with on-going enrollment.

Conclusions

The combination of these two studies yields evidence of poor context processing ability associated with cocaine dependence. However, the pattern of performance in these studies did not allow for the presence of a specific deficit in context processing to be interpreted. Thus, whether poor context processing skills underlie the widespread cognitive impairments commonly associated with cocaine misuse remains unclear. Results of poor context processing ability in individuals dependent upon cocaine raises the possibility that this impairment may play a role in the difficulty that chronic cocaine users often experience when attempting to change their habitual behavior and remain abstinent. While information regarding the level of context processing skills in individuals dependent on cocaine is pertinent, further progress in this domain will likely require techniques that can differentiate specific from generalized deficits. Results from future research will hopefully shed light on whether context processing impairment associated with cocaine dependence is a process-specific deficit that contributes in turn to users' generalized cognitive impairments.

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Figure 1.

a. Between-groups difference in d -context in Study 1; b. Error rates of performance on expectancy-AX task in Study 1; c. Between-groups difference in d -context in Study 2; d. Error rates of performance on DPX task in Study 2.

Table 1

Profile for control and cocaine dependent participants

	Cocaine Dependent	Control	Statistical Significance
Study 1	n=34	n=24	
Sex (% male)	52	50	$\chi^2 = .017, p = 0.9$
Age (years)	40.2 (8.1)	38.7 (8.9)	$t = -.59, p = 0.56$
Education (years)	13.3 (1.6)	15.2 (1.6)	$t = 3.716, p = 0.001$
Race (% majority) ^b	28.0	88.9	$\chi^2 = 21.5, p < 0.001$
Cocaine use (years)	18.9 (8.4)	0	-
Study 2	n=31	n=31	
Sex (% male)	81	74	$\chi^2 = .2, p = .65$
Age (years)	35.8 (8.3)	37.7 (8.2)	$t = -.88, p = .38$
Education (years)	13.1 (1.5)	15.1 (1.6)	$t = 5.13, p < .001$
Race (% majority) ^b	79.3	64.5	$\chi^2 = 3.81, p = .43$
Cocaine use (years)	15.3 (7.0)	0	-

^aDemographic information was not available for 15 participants in Study 1 (6 in control group and 9 in CocDep group).

^bMajority is defined as white or Caucasian. The minority included: American Indian or Native Alaskan, Asian, Black or African American.