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Looking Through the Lens of Individual Differences: Relationships Between Personality, Cognitive Control, Language Processing, and Genes

Ranjani Prabhakaran
University of Pennsylvania, prabhakr@psych.upenn.edu

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Abstract

The study of individual differences in cognitive abilities and personality traits has the potential to inform our understanding of how the processing mechanisms underlying different behaviors are organized. In the current set of studies, we applied an individual-differences approach to the study of sources of variation in individuals' personality traits, cognitive control, and linguistic ambiguity resolution abilities. In Chapter 2, we investigated the relationship between motivational personality traits and cognitive control abilities. The results demonstrated that individual differences in the personality traits of approach and avoidance predict performance on verbal and nonverbal versions of the Stroop task. These results are suggestive of a hemisphere-specific organization of approach/avoidance personality traits and verbal/nonverbal cognitive control abilities. Furthermore, these results are consistent with previous findings of hemispheric asymmetry in terms of the distribution of dopaminergic and norephinephrine signaling pathways. In Chapter 3, we investigated the extent to which the same processing mechanisms are used to resolve lexical and syntactic conflict. In addition, we incorporated a behavioral genetics approach to investigate this commonality at the neurotransmitter level. We explored whether genetic variation in catechol-O-methyltransferase (COMT), a gene that regulates the catabolism of dopamine in prefrontal cortex, is related to individuals' ability to resolve lexical and syntactic conflict. The results of this study demonstrated that individual differences in the ability to resolve lexical conflict are related to variation in syntactic conflict resolution abilities. This finding supports constraint satisfaction theories of language processing. We also showed that those individuals with the variant of the COMT gene resulting in less availability of dopamine at the synapse tended to have greater difficulty processing both lexical and syntactic ambiguities. These results provide novel evidence that dopamine plays a role in linguistic ambiguity resolution. In sum, the results from the current set of studies reveal how an individual-differences approach can be used to investigate several different factors involved in the context-dependent regulation of behavior.

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LOOKING THROUGH THE LENS OF INDIVIDUAL DIFFERENCES: RELATIONSHIPS BETWEEN PERSONALITY, COGNITIVE CONTROL, LANGUAGE PROCESSING, AND GENES

Ranjani Prabhakaran

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Supervisor of Dissertation

____

Sharon L. Thompson-Schill, Professor, Psychology

Graduate Group Chairperson

____

Michael J. Kahana, Professor, Psychology

Dissertation Committee:
Geoffrey K. Aguirre, Assistant Professor, Neurology
Michael J. Kahana, Professor, Psychology
Sharon L. Thompson-Schill, Professor, Psychology
John C. Trueswell, Professor, Psychology

Looking Through the Lens of Individual Differences: Relationships between Personality, Cognitive Control, Language Processing, and Genes

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ABSTRACT

LOOKING THROUGH THE LENS OF INDIVIDUAL DIFFERENCES: RELATIONSHIPS BETWEEN PERSONALITY, COGNITIVE CONTROL, LANGUAGE PROCESSING, AND GENES

Ranjani Prabhakaran

Sharon L. Thompson-Schill

The study of individual differences in cognitive abilities and personality traits has the potential to inform our understanding of how the processing mechanisms underlying different behaviors are organized. In the current set of studies, we applied an individual-differences approach to the study of sources of variation in individuals' personality traits, cognitive control, and linguistic ambiguity resolution abilities. In Chapter 2, we investigated the relationship between motivational personality traits and cognitive control abilities. The results demonstrated that individual differences in the personality traits of approach and avoidance predict performance on verbal and nonverbal versions of the Stroop task. These results are suggestive of a hemisphere-specific organization of approach/avoidance personality traits and verbal/nonverbal cognitive control abilities. Furthermore, these results are consistent with previous findings of hemispheric asymmetry in terms of the distribution of dopaminergic and norephinephrine signaling pathways. In Chapter 3, we investigated the extent to which the same processing mechanisms are used to resolve lexical and syntactic conflict. In addition, we incorporated a behavioral genetics approach to investigate this commonality at the neurotransmitter level. We explored whether genetic variation in catechol-*O*-methyltransferase (*COMT*), a gene that regulates the catabolism of dopamine in prefrontal cortex, is related to individuals' ability to resolve lexical and syntactic conflict. The results of this study demonstrated that individual differences in the ability to resolve lexical conflict are related to variation in syntactic conflict resolution abilities. This finding supports constraint satisfaction theories of language processing. We also showed that those individuals with the variant of the *COMT* gene resulting in less availability of dopamine at the synapse tended to have greater difficulty processing both lexical and syntactic ambiguities. These results provide novel evidence that dopamine plays a role in linguistic ambiguity resolution. In sum, the results from the current set of studies reveal how an individual-differences approach can be used to investigate several different factors involved in the context-dependent regulation of behavior.

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CHAPTER 1: GENERAL INTRODUCTION

That individuals within a species demonstrate variation is hardly a new observation. In his seminal work, *On the Origin of Species*, Charles Darwin (1859) noted the following:

> No one supposes that all the individuals of the same species are cast in the same actual mould…These individual differences generally affect what naturalists consider unimportant parts; but I could show by a long catalogue of facts, that parts which must be called important, whether viewed under a physiological or classificatory point of view, sometimes vary in the individuals of the same species. (p. 31)

Despite the recognition that individuals demonstrate variation across behaviors, much of the research in the field of experimental psychology has viewed human behavior through the lens of the *group*. That is, the individual has only been considered in so far as he or she contributes to the estimate of central tendency for the particular behavior being studied. The source of variation around this central tendency in individuals' behaviors has long been viewed as a source of noise in studies aimed at uncovering the commonalities across humans (Cronbach, 1957; Kosslyn et al., 2002; Thompson-Schill, Braver, & Jonides, 2005). By using the group as a means of sculpting psychological theory, the field of experimental psychology rests on the assumption that individual and group are inter-changeable. However, as indicated by Darwin's observations as well as our own in everyday life, this is clearly not the case. Researchers thus run the risk of drawing erroneous conclusions about the individual. In an introduction to a special issue of *Cognitive, Affective, & Behavioral Neuroscience* on the topic of individual-differences research, Thompson-Schill et al. (2005) cautioned that "in some cases the estimate of the sample mean might not actually describe *anyone* very well. Finally, and most importantly, the mark of a theory's explanatory power is the degree to which it makes successful predictions not only about the central tendency of a population, but also about the individuals within that population" (p.115).

Based on these lines of reasoning, several researchers have advocated for an approach that employs both a group-based (experimental) *and* an individual-based (correlational) view of behavior. Cronbach (1957) urged for such a union, noting that as a result of combining these approaches, "we will come to realize that organism and treatment are an inseparable pair and that no psychologists can dismiss one of the other as error variance" (p. 683). Years later, Kosslyn et al. (2002) stressed the importance of unifying these two approaches to psychology by providing several examples of how the study of individual differences can be used to shed light on the processing mechanisms underlying behavioral phenomena, such as mental imagery (see also Thompson-Schill et al., 2005). Despite the initial reluctance of the field of experimental psychology, the use of an individual-differences approach has become more prevalent in recent times in several domains of psychology, including personality, decision-making, social reasoning, perceptual processing, and cognitive control abilities.

In the studies described in Chapters 2 and 3, we applied an individual-differences approach to the study of the following topics. In Chapter 2, we investigated the interaction between motivational personality traits and cognitive control abilities. In Chapter 3, we investigated the extent to which the same processing mechanisms are used to resolve ambiguities across lexical and syntactic domains of language processing. Furthermore, we incorporated a behavioral genetics approach to investigate this commonality at the neurotransmitter level. Below, we describe these topics in more detail as well as the utility of applying an individual-differences approach to their study.

Cognitive control has served as the focus of much research aimed at uncovering the nature of the processing mechanisms that flexibly guide goal-directed behavior. Several researchers have used an individual-differences approach to determine the "atoms" of cognitive control. Miyake and colleagues (e.g. Friedman & Miyake, 2004; Friedman et al., 2008; Miyake et al., 2000) have found related, yet separable, components of cognitive control comprising response inhibition ("the ability to inhibit dominant, automatic, or prepotent responses"), updating ("the ability to monitor incoming information for relevance to the task at hand and then appropriately update by replacing old, no longer relevant information with newer, more relevant information"), and set-shifting ("the ability to flexibly shift back and forth between tasks or mental sets") (Friedman et al., 2008, p. 201). A parallel line of individual-differences research involves the study of affective personality traits related to goal-directed behavior, or motivational personality traits. Approach, or sensitivity to reward and positive affect, and avoidance, or sensitivity to punishment and negative affect, are thought to comprise fundamental dimensions of personality (see Carver, Sutton, & Scheier, 2000; Elliot & Thrash, 2002). Davidson and colleagues (e.g. Davidson, 1992; Davidson & Fox, 1989; Sutton & Davidson, 1997) have amassed a great deal of evidence showing that individual differences in approach and avoidance sensitivity are related to hemispheric asymmetry of neural activity. Whereas individuals with higher approach sensitivity demonstrate greater left prefrontal activity, those with higher avoidance sensitivity tend to demonstrate greater right prefrontal activity.

These lines of research have merged due to the demonstration that personality and emotion can influence cognitive control abilities (see Gray, 2004 for a review). Emotion has been viewed as a form of context, such that emotional states and personality traits can flexibly modulate and guide goal-directed behavior (Gray & Braver, 2002; Revelle, 1993). The study of the interaction between emotion and cognitive control has been used to shed light on the neural organization of these processing mechanisms. Similar to the hemispheric asymmetry described above for approach and avoidance sensitivities, several researchers have suggested that verbal and nonverbal working memory systems are organized in a hemispheric-specific fashion (e.g. Smith & Jonides, 1999). Although there is evidence to suggest that approach and avoidance states are differentially associated with verbal and nonverbal working memory (Gray, 2001; Gray, Braver, & Raichle, 2002; Shackman et al., 2006), previous studies have tended to use working memory tasks that tap several different processing mechanisms. Thus, it remains unclear as to whether these domain-specific relationships also apply to cognitive control abilities.

The goal of Chapter 2 of this dissertation was to refine our understanding of the interaction between personality and cognitive control. By using the Stroop task, which isolates a single cognitive control factor (response inhibition), and manipulating content domain (verbal/nonverbal), we were able to examine the association between approach and avoidance with verbal and nonverbal cognitive control abilities. Furthermore, we investigated approach and avoidance sensitivity at the *trait* level, in contrast to the state manipulations employed by Gray and colleagues (2001, 2002). This allowed us to explore the relationship between variation in performance on one of the most commonly used tasks in cognitive control research and variation in stable personality characteristics. This approach builds on the findings that individuals can vary in both personality traits as well as in their cognitive control abilities and goes beyond these findings to ask how individual differences in one system are associated with individual differences in the other.

Whereas the focus of Chapter 2 was elucidating the differences between cognitive control abilities in verbal and nonverbal domains in terms of their relationships with personality traits, in Chapter 3 we investigated the extent to which there is commonality between ambiguity resolution mechanisms. Ambiguity serves as a source of conflict between competing representations and responses in a variety of domains of cognition. In language processing, a great deal of research has focused on the processing mechanisms underlying the resolution of lexical and syntactic ambiguities. Whereas some researchers have argued that separate mechanisms resolve lexical and syntactic ambiguities (e.g. Frazier & Rayner, 1982; Ferreira & Clifton, 1986; van Gompel, Pickering, & Traxler, 2001), others have contended that the same processing mechanisms are used to resolve both types of linguistic ambiguities (e.g. MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994). These latter theories, known as “constraint-satisfaction” or “constraint-based lexicalist” theories of language processing, propose that syntactic ambiguities are actually ambiguities at the lexical level, and are thus processed using the same mechanisms. Inherent in this assertion is an individual-differences prediction: namely, that there should be correlated variation in individuals’ abilities to resolve lexical and syntactic ambiguities. Indeed, this result is necessary to obtain in order to endorse constraint-satisfaction theories of language processing; yet, this relationship has not yet been investigated. In an article entitled “Individual Differences as a Crucible in Theory Construction”, Benton Underwood (1975) outlined the importance of an individual-differences approach to experimental psychology research. In particular, Underwood suggested that individual differences should be used as a necessary component of theory construction and evaluation. Thus, if a theory predicts a relationship between processes A and B, this is fundamentally an individual differences prediction. If, in fact, the measure of a subject’s process A turns out to be unrelated (i.e. shows a zero correlation) to the measure of the subject’s process B, this evidence should be used to modify, or in some cases, reject the theory. Thus, as an essential test of constraint-satisfaction theory, Chapter 3 describes our investigation of the relationship between subjects’ abilities to resolve lexical and syntactic ambiguities.

An important additional consideration concerns the nature of this linguistic ambiguity resolution mechanism. That is, if there is commonality in processing across lexical and syntactic ambiguity resolution tasks, what can we say about *how* this mechanism operates? Evidence from recent neuroimaging (e.g. January, Trueswell, & Thompson-Schill, 2009; Ye & Zhou, 2009) and neuropsychological studies (e.g. Novick, Kan, Trueswell, & Thompson-Schill, 2009) suggests that more general cognitive control mechanisms may underlie the resolution of linguistic ambiguities. In Chapter 3, we used a behavioral genetics approach to further explore this hypothesis. Recent developments in behavioral genetics have enabled the investigation of individual differences at the level of the gene. The study of individual differences at multiple levels spanning behavior and genes allows for a more comprehensive and powerful examination of the sources of variation in humans. In Chapter 3, we demonstrate how the application of behavioral genetic techniques to the study of linguistic ambiguity resolution mechanisms illustrates the commonality across these mechanisms at the neurotransmitter level. In particular, we explored whether genetic variation in catechol-*O*-methyltransferase (*COMT*), a gene responsible for the regulation of dopamine levels in prefrontal cortex and associated with variation in cognitive control abilities (see Goldberg & Weinberger, 2004 for a review), is related to both syntactic and lexical ambiguity resolution abilities. The use of this approach allowed us to bridge the literatures on genetic variation in *COMT*, cognitive control abilities, and the processing mechanisms underlying linguistic ambiguity resolution. As Underwood (1975) stated, “The whole idea behind behavioral theory is to reduce the number of independent processes to a minimum; to find that performance on two apparently diverse tasks is mediated at least in part by a single, more elementary, process is a step toward this long-range goal" (p. 133). The study described in Chapter 3 represents such a step.

In sum, the goal of the studies presented in Chapters 2 and 3 was to use an individual-differences approach to shed light on the processing mechanisms underlying the context-dependent regulation of behavior.

CHAPTER 2: PERSONALITY TRAITS PREDICT COGNITIVE CONTROL ABILITIES

Abstract

Previous studies suggest that the personality traits of approach and avoidance impact cognitive control abilities. However, the nature of this relationship remains unclear. In the current study, we aimed to address the following two questions: 1) Do approach and avoidance predict individual differences in a specific cognitive control ability, namely the ability to respond based on task-relevant information while ignoring task-irrelevant information, and 2) Are these personality traits differentially associated with verbal and nonverbal cognitive control abilities? The findings from the current study indicate that approach and avoidance trait sensitivities predict Stroop performance. Furthermore, whereas approach sensitivity was predictive of verbal Stroop performance, avoidance sensitivity was predictive of nonverbal Stroop performance. We discuss these results in the context of prior literature reporting differential distribution of neurochemical pathways across the left and right hemispheres and note that the current findings are suggestive of the integration of emotion and cognition in a hemisphere-specific manner.

Introduction

The relationship between personality traits and behavior has long served as a topic of interest in psychology. Several researchers have proposed that the motivational personality traits or "affective styles" (Davidson, 1992) of approach and avoidance serve as fundamental dimensions of personality and behavior (e.g. Carver, Sutton, & Scheier, 2000; Elliot & Thrash, 2002). Approach motivation refers to behavior toward desired stimuli, sensitivity to reward cues, and is associated with positive affective states. Avoidance motivation is characterized by behavior away from aversive stimuli, sensitivity to punishment cues, and is associated with negative affective states (see Carver et al., 2000 for a review). Indeed, a great deal of prior animal research suggests that approach and avoidance constitute core motivational systems guiding behavior that rely on distinct neural substrates (Gray, 1972; 1990; Schneirla, 1959). The behavioral activation system (BAS), which facilitates approach behavior and demonstrates responsivity to reward cues, is thought to be mediated by dopaminergic pathways (Depue & Collins, 1999). The behavioral inhibition system (BIS), which facilitates avoidance and is associated with sensitivity to punishment, has been linked to functioning of the septo-hippocampal system (Gray, 1972).

Much of the evidence for the mapping of BAS and BIS sensitivities onto neural substrates in humans comes from electroencephalogram (EEG) and neuroimaging studies demonstrating a relationship between positive affective state and trait variables and greater left frontal activity, on the one hand, and negative affective state and trait variables and greater right frontal activity, on the other hand (e.g. Harmon-Jones &

Gable, 2009; Herrington et al., 2005; Sutton & Davidson, 1997; c.f. Coan & Allen, 2003). This frontal cortical asymmetry has been more specifically related to the distinction between approach and avoidance motivation in particular, rather than positive and negative affect in general (e.g. Gable & Harmon-Jones, 2008; Harmon-Jones, 2003). Additionally, the extent to which positive affective states tap approach motivation has been found to influence the type of attentional processes recruited in a given task and the extent of relative left frontal cortical activity (see Harmon-Jones & Gable, 2009; Rowe, Hirsh, & Anderson, 2007). For example, Rowe, Hirsh, & Anderson (2007) demonstrated that the inducement of a positive emotional state resulted in increased interference effects on the flanker task relative to neutral or sad emotional states. From this finding, Rowe et al. (2007) concluded that positive affective states serve to broaden or increase the scope of perceptual attention. In contrast, Gable & Harmon-Jones (2008; 2009) have shown that positive affect high in approach motivation results in a reduced scope of attention, reflected in reduced focus on global versus local components of stimuli, and increased relative left frontal activity. These results suggest the importance of motivational variables in impacting cognitive control abilities (see also Amodio, Master, Yee, & Taylor, 2008; Gray, 2004; Gray, Braver, & Raichle, 2002; Revelle, 1993).

Previous evidence also suggests that approach and avoidance motivation may be differentially associated with verbal and nonverbal cognitive control abilities. Gray (2001) demonstrated that the induction of approach motivational states improved verbal working memory performance and impaired spatial working memory performance, whereas avoidance motivational states improved spatial working memory performance and impaired verbal working memory performance (see also Shackman et al., 2006). Gray (2001) suggested that these selective influences of motivational states on cognitive control abilities may stem from hemispheric lateralization underlying both approach/avoidance motivation and verbal/nonverbal working memory. That is, the left hemisphere may support both verbal working memory and approach motivation, whereas the right hemisphere may support both nonverbal/spatial working memory and avoidance motivation (see also Heller & Nitschke, 1997). Although Gray's (2001) findings provide intriguing evidence for selective modulation of cognitive control abilities by different motivational states, they also raise several questions. For example, do approach and avoidance motivations impact specific cognitive control abilities? The n-back task, which was used in Gray (2001), taps several different processing mechanisms, including active maintenance, updating, and response selection (Smith & Jonides, 1997). Thus, the locus of impact of approach and avoidance sensitivity on verbal and nonverbal cognitive control abilities requires further investigation.

Additionally, Gray (2001) focused on the role of motivational *states* in influencing verbal and nonverbal working memory performance, noting that those subjects with higher levels of approach and avoidance motivation at the trait level demonstrated increased effects of the motivational state induction on working memory performance. In the current study, we sought to determine whether individual differences in *trait* motivation, in the absence of state inductions, predict verbal and nonverbal cognitive control abilities. If so, this finding would have important implications for our understanding of the processing mechanisms underlying both motivational and cognitive control systems. Additionally, this finding has the potential to uncover a source of variability in subjects' cognitive control abilities, a topic of study for a vast number of laboratory experiments in cognitive psychology.

Another question raised by previous research concerns the relationship between other dimensions of personality and cognitive control abilities. Extraversion and Neuroticism have been proposed as two dimensions of personality that are associated with positive and negative affect, respectively (Eysenck & Eysenck, 1964). Lieberman (2000) has suggested that extraverts are characterized by more efficient central executive processing compared to introverts (c.f. Gray, 2001). These findings raise the question of whether Extraversion and Neuroticism modulate cognitive control abilities in a selective fashion, similar to BIS and BAS sensitivity. Furthermore, it has been proposed that the commonality across different dimensions of personality lies in the distinction between approach and avoidance motivation (e.g. Elliot & Thrash, 2002; Carver et al., 2000). Elliot and Thrash (2002) demonstrated that measures of positive affective disposition, Extraversion, and BAS loaded on a single factor, which they labeled as Approach Temperament, and measures of negative affective disposition, Neuroticism, and BIS loaded on a different factor, labeled as Avoidance Temperament. Based on these results, Elliot and Thrash (2002) suggested that Approach and Avoidance Temperaments represent core dimensions of personality that guide goal-directed behavior.

The goals of the current study were two-fold. First, we sought to determine whether individual differences in trait sensitivity to the BIS/BAS and Neuroticism/Extraversion dimensions are predictive of performance on the Stroop task

(Stroop, 1935), which taps a specific cognitive control ability: responding on the basis of task-relevant information while ignoring task-irrelevant information. Second, we aimed to determine whether BIS/BAS and Neuroticism/Extraversion trait sensitivity are differentially predictive of verbal and nonverbal Stroop performance. Based on the results of Gray (2001) and Elliot & Thrash (2002), we predicted that an Approach factor, reflecting the commonality across BAS and Extraversion, would predict better verbal Stroop performance (i.e. smaller conflict effects), whereas an Avoidance factor, reflecting the commonality across BIS and Neuroticism, would predict better nonverbal Stroop performance.

Methods

Participants

Seventy-nine participants (26 men, 53 women, ages 18-35) participated in this study. Data from one additional participant were excluded from all analyses due to at-chance performance on the nonverbal Stroop task. All subjects were right-handed, native speakers of English, and were not taking any psychoactive medications. Subjects were paid at the rate of $10/hour for their participation, and the testing session lasted approximately 1.5 hours. All subjects gave informed consent prior to participating in the experiment according to guidelines established by the Institutional Review Board of the University of Pennsylvania.

Materials

Verbal Stroop Task

Subjects indicated the font color of a presented color word via button press on a computer keyboard. Three possible response options were available to the subject: yellow, green, and blue. A colored square corresponding to each color was affixed to a different key on the computer keyboard, and subjects were instructed to press the key corresponding to the appropriate color as quickly and as accurately as possible. Subjects were instructed to use only their right hand when indicating their response. The verbal Stroop task featured two main types of trials: congruent and incongruent. For congruent trials, the font color matched the meaning of the word (e.g. “yellow” presented in yellow font color). Two types of incongruent trials were included (see Milham et al., 2001). For half of the incongruent trials, the font color did not match the meaning of the word, although the word did name a possible response (e.g. “yellow” presented in a blue font color). For the other half of incongruent trials, color words that were not potential response options (i.e. “red”, “brown”, “orange”) were presented in yellow, green, or blue (e.g. “red” presented in a blue font color). The inclusion of two types of incongruent trials was designed to address experimental questions that are not germane to the goals of the current study. Thus, all reported results collapse across both types of incongruent trials.

For each trial, subjects were first presented with a fixation cross for 1000 ms. The stimulus was then presented for 1500 ms, followed by a 500 ms inter-trial interval consisting of a blank screen. Subjects completed four blocks of each task, where each block comprised 72 trials: 36 congruent trials and 36 incongruent trials. Trials were presented in a fixed pseudo-randomized order across all subjects. Subjects also performed 24 practice trials (12 congruent trials and 12 incongruent trials) prior to the task in order to familiarize them with the stimuli and task procedures. Stimuli were presented and responses were collected with E-prime software (Schneider, Eschman, & Zuccolotto, 2002).

Nonverbal Stroop Task

A novel variant of the nonverbal Stroop task that was originally developed by Pomerantz (1983) was used in the current study. Subjects viewed a moving square window (global motion) containing moving dots (local motion) and indicated the direction of (local) motion of the dots, by pressing either the left or right key of two designated keys on a computer keyboard. Subjects were instructed to use only their right hand when indicating their response. The window and dots appeared in black and were presented on a white background. As in the verbal Stroop task, subjects were presented with two types of trials: congruent and incongruent. For congruent trials, local and global motion occurred in the same direction (e.g. window moving to the right containing dots moving to the right). Two types of incongruent trials were included. For half of the incongruent trials, local motion occurred in the direction opposite of global motion, which was also a potential response option (e.g. window moving to the left containing dots moving to the right). For the other half of incongruent trials, global motion occurred in either the up or down direction, which were not potential response options (e.g. window moving up containing dots moving to the right). As for the verbal Stroop task, all reported results collapse across both types of incongruent trials for the nonverbal Stroop task.

Trial timing parameters and the number of trials in each condition were the same as for the verbal Stroop task described above. Stimuli were presented and responses were collected with MATLAB® software (2007a, The Mathworks).

Behavioral Inhibition/Behavioral Activation Scales (BIS/BAS)

Subjects completed the BIS/BAS scales (Carver & White, 1994). These scales were developed to assess trait sensitivity to the punishment (BIS) and reward (BAS) responsive systems. The BIS scale consists of 7 items, each of which is designed to assess individuals' sensitivity to punishment cues (e.g. "If I think something unpleasant is going to happen, I get pretty worked up"). The BAS scale consists of a total of 13 items, each of which assesses individuals' sensitivity to cues of reward. The BAS scale comprises three sub-scales: BAS-Drive (4 items; e.g. "When I want something, I usually go all-out to get it"), BAS-Fun Seeking (4 items; e.g. "I'm always willing to try something new if I think it will be fun"), and BAS-Reward Responsiveness (5 items; e.g. "When good things happen to me, it affects me strongly"). Subjects responded using a scale ranging from 1 (strongly disagree) to 4 (strongly agree). The sums of responses to items from each scale were used as BIS and BAS scores in further analyses. BAS scores correspond to the sum of responses to items from the three BAS subscales.

Carver & White (1994) demonstrated the high internal reliability (α ranging from 0.66 – 0.76) and high test-retest reliability (ranging from 0.59-0.69) for these scales. Additionally, Carver & White (1994) demonstrated the convergent and discriminant validity of the BIS/BAS scales as well as their predictive power by showing that subjects' BIS scores were predictive of self-reported anxiety in response to punishment, and subjects' BAS scores were predictive of self-reported happiness levels in response to reward.

Eysenck Personality Inventory (Form A)

Subjects completed Form A of the Eysenck Personality Inventory (Eysenck & Eysenck, 1964), which comprises the following dimensions: Extraversion (24 items, e.g. "Do other people think of you as being very lively?"), Neuroticism (24 items, e.g. "Would you call yourself tense or highly strung?"), and Lie (9 items, e.g. "Are all your habits good and desirable ones?"). The Neuroticism scale was designed to measure subjects' tendency to experience negative affect, whereas the Extraversion scale was designed to assess subjects' sociability, impulsivity, and activity levels. Subjects responded by pressing either "1" (yes) or "2" (no). "No" responses were later recoded as "0" for scoring purposes. The interpretation of the Lie dimension has been the subject of debate (see Knowles & Kreitman, 1965), and as it does not constitute the focus of the current study, we report only the results from the Extraversion and Neuroticism scales. Several studies (e.g. Eysenck & Eysenck, 1964) have demonstrated the high internal reliability (α ranging from 0.80 – 0.90) and high test-retest reliability (ranging from 0.85 – 0.94) of the Extraversion and Neuroticism scales.

Procedure

Subjects completed the tasks and questionnaires in the following order: Verbal Stroop, Nonverbal Stroop, BIS/BAS scales, and the Eysenck Personality Inventory (Form A). Tasks and questionnaires were administered to all subjects in the same order in order to minimize measurement error resulting from participant x task order interactions (e.g. Friedman & Miyake, 2004; Friedman et al., 2008; Miyake et al., 2000).

Statistical Procedures

Conflict effects were more robust in the first two blocks compared with all four blocks for the nonverbal Stroop task ($t[78] = 3.06, p < 0.01$). This is likely due to subjects becoming more practiced over the course of the nonverbal Stroop task, resulting in smaller conflict effects across all four blocks of the task. Thus, in order to better assess the relationship between personality variables and conflict effects, all reported results include data from only the first 2 blocks for both the verbal and nonverbal Stroop tasks.

For both verbal and nonverbal Stroop tasks, a within-subject trimming procedure recommended by Wilcox & Keselman (2003) was applied to each subject's reaction time (RT) data. For each subject and each condition, RTs whose deviation from the median was greater than 3.32 times the median absolute deviation were excluded prior to calculating mean RTs. This procedure resulted in no more than 9.4 % of observations excluded in each condition. Mean RTs and percent error rates for verbal and nonverbal Stroop tasks are presented in Table 2.1. RT conflict effects expressed as difference scores (incongruent RT – congruent RT) and as percentage RT conflict effects [(incongruent RT – congruent RT)/congruent RT] are presented in Table 2.2. Only correct trials were included in all RT analyses.

Due to low error rates for both verbal and nonverbal Stroop tasks, all correlational analyses were performed on the RT data, which revealed more robust conflict effects. Furthermore, in order to ensure that these correlations did not merely reflect effects of personality variables on overall speed for congruent and incongruent conditions, all correlations were calculated using percentage RT conflict effects. In order to improve normality and reduce the influence of extreme values, an additional trimming procedure was employed. Observations greater than three standard deviations from the group mean were replaced with observations three standard deviations from the mean for each variable included in correlational analyses (see Friedman et al., 2008). No more than 1.3 % of the observations for each variable were affected by this additional trimming procedure.

Results

BIS/BAS Scales & Eysenck Personality Inventory (Form A)

Means, standard deviations, ranges, reliabilities, and correlations for the BIS, BAS, Neuroticism, and Extraversion scales are presented in Table 2.3. These values are similar to those reported in previous studies using these measures (e.g. Carver & White, 1994; Gray, 2001; Knowles & Kreitman, 1965). BIS and total BAS scores (across all three subscales) were not significantly correlated, and Neuroticism and Extraversion scores were also not significantly correlated. In order to ensure the independent contributions of BIS and BAS scores to Stroop performance, all reported correlations with BIS scores control for BAS scores (and vice versa). Additionally, in order to present the correlations with Neuroticism and Extraversion in a parallel fashion to the BIS/BAS results, all reported correlations with Neuroticism scores control for Extraversion scores (and vice versa).

Stroop Performance

For the verbal Stroop task, subjects demonstrated significantly longer reaction times ($t[78] = 13.68$, $p < 0.001$) and higher error rates ($t[78] = 4.14$, $p < 0.001$) for incongruent compared to congruent trials. Similarly, for the nonverbal Stroop task, subjects demonstrated significantly longer reaction times ($t[78] = 5.60$, $p < 0.001$) and higher error rates ($t[78] = 5.27$, $p < 0.001$) for incongruent compared to congruent trials.

Verbal Stroop & Personality

We first examined the relationship between reaction times for verbal Stroop congruent and incongruent conditions with BIS/BAS and Neuroticism/Extraversion scores. Separate repeated measures ANCOVAs were performed for BIS/BAS and Neuroticism/Extraversion, with condition (congruent/incongruent) as a within-subjects factor, and BIS/BAS and Neuroticism/Extraversion scores as covariates. A significant BAS x condition interaction effect ($F[1,76] = 4.10$, $p < 0.05$) and a marginally significant Extraversion x condition interaction effect ($F[1,76] = 3.52$, $p = 0.064$) were found. The condition x BIS and condition x Neuroticism interaction effects failed to approach significance (F's < 1).

In order to examine these interaction effects with BAS and Extraversion further, correlations were calculated between these personality measures and verbal Stroop percentage RT conflict effects. A marginally significant negative correlation was found between verbal Stroop percentage RT conflict and BAS total scores ($r = -0.20$, $p = 0.076$) (Figure 2.1 A)[1]. Additionally, a significant negative correlation was found between

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[1] All reported correlations were also calculated without controlling for the relevant personality variables, and both correlational and partial correlational analyses yielded similar results. All reported correlations in the text are partial correlations in order to ensure the independent contributions of personality variables to

Extraversion and verbal Stroop percentage RT conflict effects ($r = -0.223$, $p < 0.05$) (Figure 2.1 B). Thus, those subjects who had higher BAS and Extraversion scores tended to demonstrate smaller verbal Stroop conflict effects.

Nonverbal Stroop & Personality

As for the verbal Stroop task, separate repeated measures ANCOVAs were performed for BIS/BAS and Neuroticism/Extraversion, with condition (congruent/incongruent) as a within-subjects factor, and BIS/BAS and Neuroticism/Extraversion scores as covariates. A significant BIS x condition interaction effect ($F[1,76] = 4.72$, $p < 0.05$) and marginally significant Neuroticism x condition interaction effect ($F[1,76] = 2.92$, $p = 0.092$) were found. Interestingly, we also found a marginally significant condition x Extraversion interaction effect ($F[1,76] = 3.33$, $p = 0.072$). However, the condition x BAS interaction effect failed to approach significance ($F < 1$).

We further investigated the interaction effects with BIS, Neuroticism, and Extraversion by calculating correlations between these measures and nonverbal Stroop percentage RT conflict effects. We found a significant relationship between BIS scores and nonverbal Stroop percentage RT conflict effects ($r = 0.25$, $p < 0.05$) (Figure 2.2 A); however, the correlation between Neuroticism scores and nonverbal Stroop percentage RT conflict effects failed to reach significance ($r = 0.17$, $p = 0.13$) (Figure 2.2 B). Interestingly, both of these correlations were in the positive direction, indicating that higher self-reported BIS and Neuroticism predicted larger nonverbal Stroop conflict

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verbal and nonverbal Stroop conflict effects. However, for ease of interpretability of the axes representing personality measures, all correlations depicted in Figures 1 and 2 represent correlations between the personality measures and conflict effects, without controlling for other personality variables.

effects. We return to potential explanations for these findings in the Discussion section. A marginally significant negative correlation was also found between Extraversion and nonverbal Stroop percentage RT conflict effects ($r = -0.22$, $p = 0.053$).

Approach/Avoidance Factors & Stroop Performance: Exploratory Factor Analysis

A principal components exploratory factor analysis (EFA) using varimax rotation was performed on the following six personality variables: BAS-Reward Responsiveness, BAS-Fun Seeking, BAS-Drive, Extraversion, BIS, and Neuroticism scores.[2] Two factors with eigenvalues greater than 1.0 were obtained. The first factor, on which the BAS subscales and Extraversion loaded most highly, accounted for 37.28 % of the variance. The second factor, on which the BIS and Neuroticism scales loaded most highly, accounted for 25.89 % of the variance. Factor loadings for both factors are presented in Table 2.4. These results indicate two distinct factors that are similar to the Approach and Avoidance Temperaments derived by Elliot & Thrash (2002).

We next correlated regression factor scores for the Approach and Avoidance factors with subjects' verbal and nonverbal Stroop percentage RT conflict effects. The Approach factor score predicted smaller verbal Stroop percentage RT conflict effects ($r = -0.24$, $p < 0.05$) (Figure 2.1 C); however, the Approach factor score was not significantly associated with subjects' nonverbal Stroop percentage RT conflict effects ($r = -0.09$, $p = 0.42$). The Avoidance factor score predicted larger nonverbal Stroop percentage RT conflict effects ($r = 0.23$, $p < 0.05$) (Figure 2.2 C); however, the Avoidance factor score

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[2] A principal components EFA was also performed using direct oblimin rotation. This EFA yielded highly similar factor loadings and the same pattern of correlations between regression factor scores and verbal and nonverbal Stroop conflict effects.

was not significantly associated with subjects' verbal Stroop percentage RT conflict effects ($r = -0.03$, $p = 0.806$). Although this pattern of results is suggestive of domain-specificity, the strength of these correlations was not significantly different between verbal and nonverbal Stroop percentage RT conflict effects for the Approach or Avoidance Factors (p 's> 0.12).

Discussion

The previous literature suggests that personality traits influence cognitive control abilities. However, several of these studies (e.g. Gray, 2001; Gray et al., 2002; Shackman et al., 2006) have employed the n-back task, which precludes specification of which processing mechanisms are impacted by different motivational systems. The current study provides novel evidence indicating that approach and avoidance trait sensitivities were predictive of performance on the Stroop task, suggesting that these personality traits are associated with a specific cognitive control ability.

The results of the current study also provide novel evidence indicating that whereas approach sensitivity was predictive of verbal (and not nonverbal) Stroop performance, avoidance sensitivity was predictive of nonverbal (and not verbal) Stroop performance. The association between approach and verbal cognitive control ability, on the one hand, and avoidance and nonverbal cognitive control ability, on the other hand, is consistent with a large body of literature on hemispheric differences in affective and cognitive processing (e.g. Harmon-Jones, 2003; Harmon-Jones & Gable, 2009; Heller & Nitschke, 1997; Kelley et al., 1998; Morimoto et al., 2008; Sutton & Davidson, 1997). Gray (2001) found that approach motivational states were associated with facilitated verbal n-back performance and impaired spatial n-back performance. The opposite pattern of results was found for avoidance motivational states (c.f. Shackman et al., 2006). Our results are consistent with Gray (2001) in terms of the association between approach sensitivity and facilitated performance on a verbal cognitive control task (although not with the association between approach and impaired nonverbal cognitive control performance). However, based on Gray (2001)'s findings, we had predicted that avoidance trait sensitivity would be associated with smaller nonverbal Stroop conflict effects. That is, if the right hemisphere supports nonverbal processing and an avoidant motivational style, one might expect that individuals higher in avoidance motivation might be facilitated on the nonverbal Stroop task. However, our results indicate that higher avoidance trait sensitivity resulted in *larger* nonverbal Stroop conflict effects. What could explain this pattern of results?

One possible explanation stems from previous research suggesting that whereas the left hemisphere is specialized for local processing, the right hemisphere is specialized for global, or more holistic, processing (e.g. van Kleeck, 1989; Delis, Robertson, & Efron, 1986). Furthermore, Volberg & Hübner (2004) have demonstrated that hemispheric differences are more pronounced in situations of conflict between local and global dimensions of stimuli. In light of these results, it is important to note that the nonverbal Stroop task used in the current study involves conflict between local and global dimensions. In particular, subjects were instructed to report the direction of motion of local elements (i.e. the moving dots) in the face of interference from global motion (i.e. the moving box). Thus, a more global or holistic processing style may lead to larger nonverbal Stroop conflict effects due to increased attention to the global, irrelevant dimension of the stimulus. This account would lead one to predict that if subjects were required to focus on the global dimension of a stimulus while ignoring the local elements, greater avoidance trait sensitivity might be associated with smaller nonverbal conflict effects. This prediction as well as the relationship between avoidance trait sensitivity and performance on other nonverbal conflict tasks, including those that do not feature conflict between local and global dimensions, should be investigated in future research.

It is important to note that the strength of the correlations between approach and verbal Stroop conflict effects, on the one hand, and approach and nonverbal Stroop conflict effects, on the other hand, were not significantly different. Similarly, no significant difference was found in the strength of correlations between avoidance and verbal and nonverbal Stroop conflict effects. We do not wish to over-interpret null results, and it is possible that with a larger sample size, the correlation between approach and nonverbal Stroop (as well as the correlation between avoidance and verbal Stroop) may reach significance. Nonetheless, the pattern of results reported in the current study is suggestive of domain-specificity in the interaction between cognitive and affective processes. Although the association between approach/avoidance motivation and verbal/nonverbal cognitive control ability is consistent with previously reported results pertaining to hemispheric lateralization, the question remains as to what exactly this lateralization may reflect. As noted by Gray (2001), previous research suggests that hemispheric specialization for cognitive and affective processing may stem from differential distribution of neurotransmitter pathways across the right and left hemispheres. Whereas dopamine levels tend to be higher in the left hemisphere (Glick, Ross, & Hough, 1982), higher levels of norepinephrine and serotonin have been found in the right hemisphere (Gottfries, Perris, & Roos, 1974; Oke, Keller, Mefford, & Adams, 1978). This differential activity of neurotransmitter pathways across the left and right hemispheres has been tied to different modes of attentional processing, which in turn, have been associated with differential affective and cognitive consequences (see Tucker & Williamson, 1984 for a review). For example, the greater activity of dopamine pathways in the left hemisphere has been associated with more tonic forms of attention. The greater activity of norepinephrine and serotonin pathways in the right hemisphere has been associated with arousal and a global, receptive mode of information processing. Furthermore, research in non-human animals has implicated dopaminergic pathways in mediating extraversion and the BAS, whereas noradrenergic and serotonergic pathways have been proposed to mediate neuroticism and the BIS (Depue & Collins, 1999; Gray & McNaughton, 2000; Wallace & Newman, 1997).

In light of these previous findings, Braver, Gray, & Burgess (2008) have proposed a link between approach sensitivity and a proactive mode of cognitive control, which involves the active, sustained maintenance of task-relevant information. In contrast, Braver et al. (2008) have suggested that avoidance sensitivity may be associated with a reactive mode of cognitive control, which operates in a transient fashion and is triggered in response to a stimulus. Thus, it is possible that the greater dopamine activity in the left hemisphere underlies approach sensitivity and increased maintenance of task-relevant information, resulting in smaller conflict effects in the domain supported by the left hemisphere (i.e. verbal). In contrast, the greater activity of the norepinephrine and serotonergic systems in the right hemisphere may underlie avoidance sensitivity and a more reactive, global mode of control, resulting in larger conflict effects in the domain supported by the right hemisphere (i.e. nonverbal). Although the current study was not designed to explicitly test this hemispheric hypothesis, it appears to be a plausible explanation for the results of the current study and should be investigated in further research. Furthermore, given the demonstration of unity and diversity of executive functions (e.g. Miyake et al., 2000), future studies should investigate whether individual differences in approach and avoidance are predictive of other cognitive control abilities, such as updating and set-shifting.

In sum, we found that personality traits are associated with cognitive control abilities. Higher approach trait sensitivity was associated with increased ability to ignore task-irrelevant information in the verbal domain, whereas higher avoidance trait sensitivity was associated with decreased ability to ignore task-irrelevant information in the nonverbal domain. Furthermore, we have shown that individual differences in personality traits, in the absence of state manipulations, are associated with individual differences in cognitive control abilities. By demonstrating the association between personality traits and a specific cognitive control ability, these results serve to refine our understanding of the nature of the interaction between personality and cognition.

Table 2.1. *Performance Summary for Verbal and Nonverbal Stroop Tasks*.

Condition	**Mean RT**	***SD***	**Mean % Error**	***SD***
Verbal Stroop				
Congruent	556	81	2.4	2.4
Incongruent	611	96	4.1	4
Nonverbal Stroop				
Congruent	546	104	1.3	1.9
Incongruent	584	142	4.7	6.3

Note. RTs are given in milliseconds. *SD* corresponds to standard deviation. *N* = 79 for verbal and nonverbal Stroop tasks.

Table 2.2. *Conflict Effects for Verbal and Nonverbal Stroop Tasks.*

Conflict Condition	**RT Conflict**	***SD***	**% RT Conflict**	***SD***	**Reliability**	**Skewness**	**Kurtosis**
Verbal Stroop							
Incongruent	55	36	9.9	6	0.68	-0.101	-0.051
Nonverbal Stroop							
Incongruent	36	51	6.1	8.2	0.88	1.35	1.79

Note. Conflict condition, incongruent trials compared to the congruent condition; RT Conflict, mean reaction time difference scores in milliseconds; % RT Conflict, mean percentage RT conflict ([incongruent-congruent]/congruent); Reliability, split-half (odd-even) correlations for percentage RT conflict effects adjusted with the Spearman-Brown prophecy formula; Skewness and Kurtosis, skewness and kurtosis statistics for percentage RT conflict effects. *SD* corresponds to standard deviation. $N = 79$ for verbal and nonverbal Stroop tasks.

Table 2.3. *Descriptive Statistics for Self-Report Personality Trait Measures*.

					Zero-order correlations (*r*)		
Trait measure	**Range**	***M***	***SD***	**Reliability**	**BIS**	**BAS(Total)**	**Extraversion**
BIS	12-28	20.94	3.57	0.81	-		-
BAS (Total)	28-50	40.23	4.6	0.8	-0.142	-	-
Extraversion	6-20	11.86	3.06	0.51	-0.309 **	0.395 **	-
Neuroticism	2-23	10.82	4.92	0.82	0.593 **	-0.092	-0.039

Note. BIS = Behavioral Inhibition System; BAS (Total) = Behavioral Activation System (sum of the three BAS subscale scores). Reliability was calculated using Cronbach's alpha. SD corresponds to standard deviation. $N = 79$ for verbal and nonverbal Stroop tasks.
** $p < 0.05$.

Table 2.4. *Approach and Avoidance Factor Loadings*.

	Factor Loadings	
Trait measure	**Approach**	**Avoidance**
BAS Reward Responsiveness	0.76	0.27
BAS Drive	0.69	0.04
BAS Fun Seeking	0.76	-0.35
Extraversion	0.60	-0.33
BIS	-0.12	0.91
Neuroticism	0.03	0.8

Note. BAS = Behavioral Activation System; BIS = Behavioral Inhibition System.

Figure Captions

Figure 2.1. Correlations between verbal percentage RT conflict effects (*N* = 79) and (A) BAS total scores (B) Extraversion scores (C) Approach factor scores. Lines shown indicate trend lines. Corresponding Pearson *r* coefficients for partial correlations controlling for relevant personality variables provided in main text.

Figure 2.2. Correlations between nonverbal percentage RT conflict effects (*N* = 79) and (A) BIS scores (B) Neuroticism scores (C) Avoidance factor scores. Lines shown indicate trend lines. Corresponding Pearson *r* coefficients for partial correlations controlling for relevant personality variables provided in main text.

Figure 2.1.

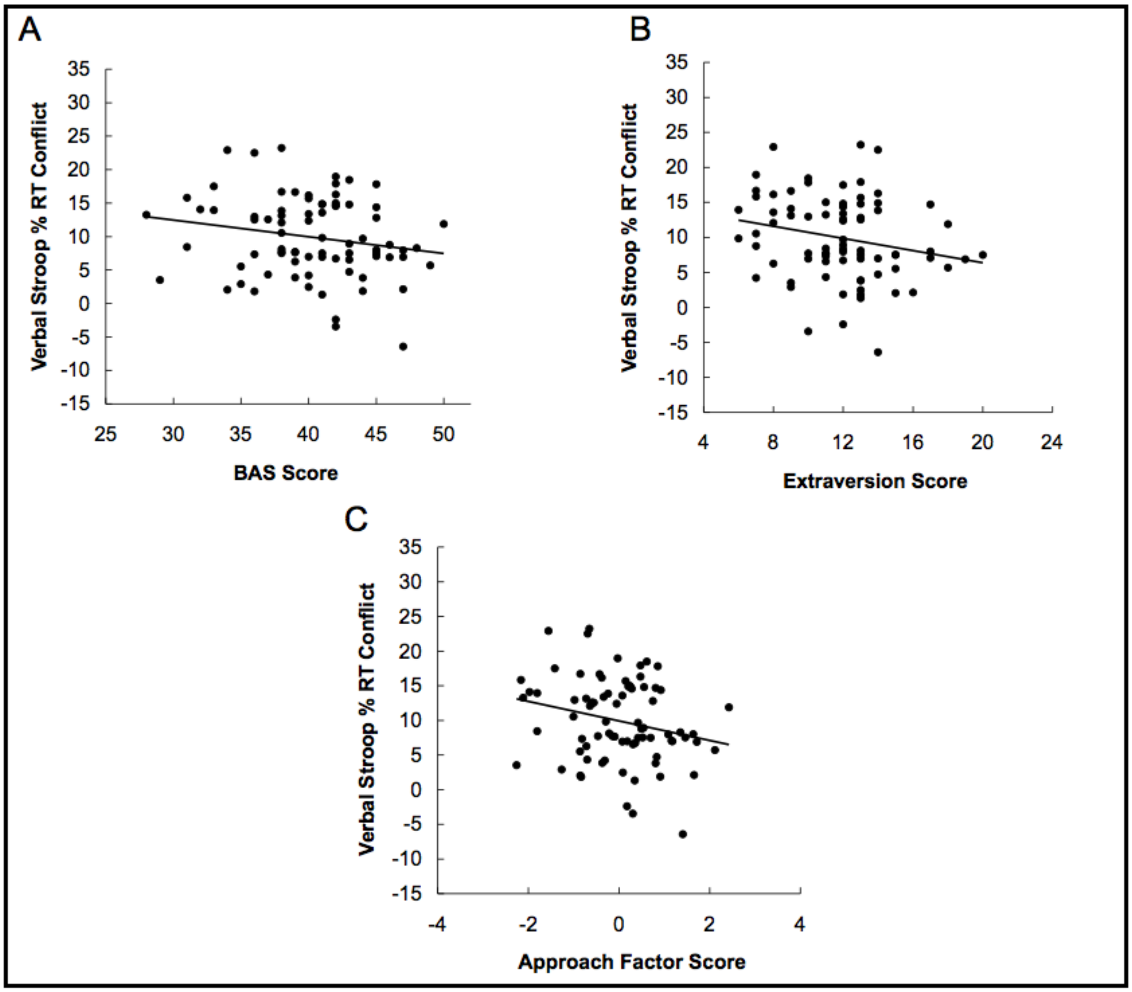
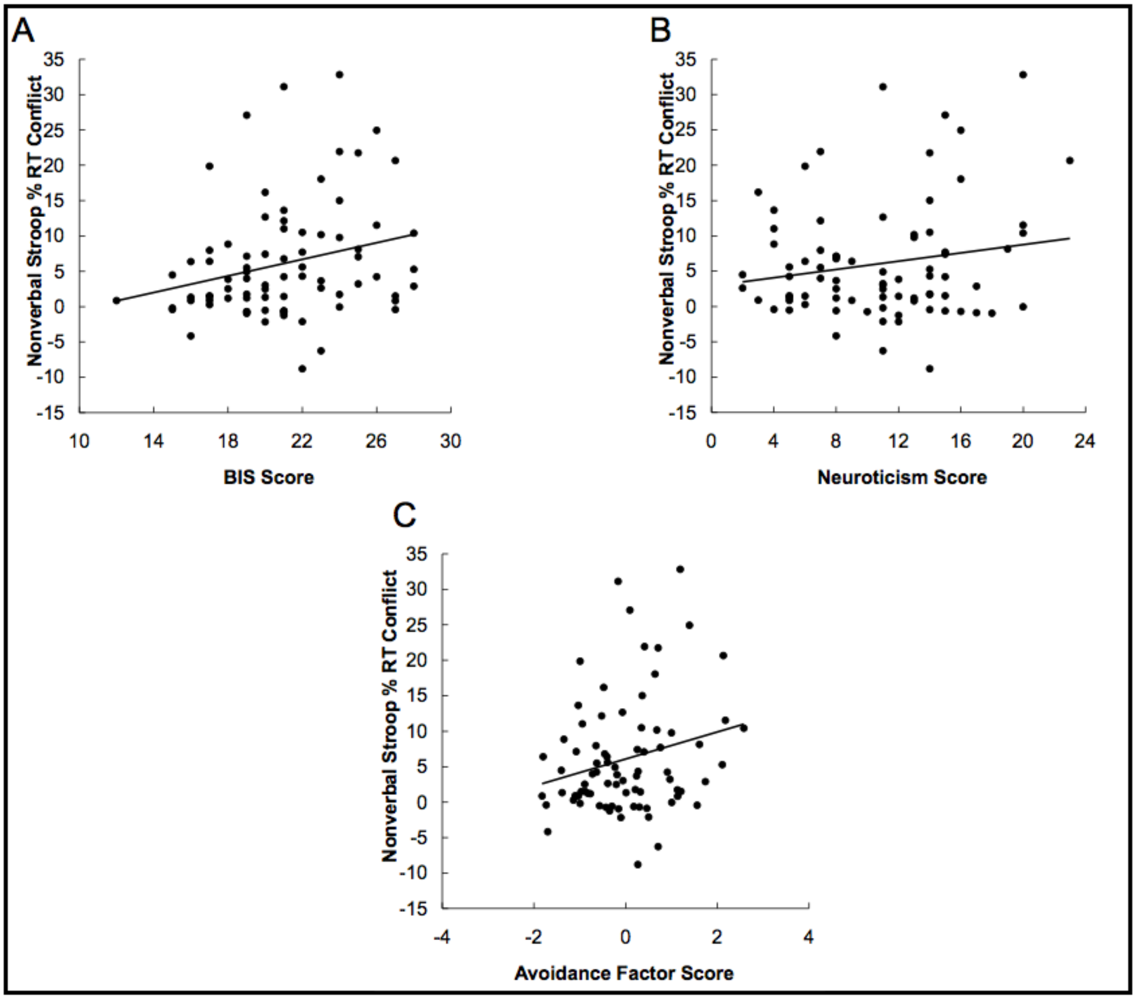

A
Verbal Stroop % RT Conflict
35
30
25
20
15
10
5
0
-5
-10
-15
25
30
35
40
45
50
BAS Score
B
Verbal Stroop % RT Conflict
35
30
25
20
15
10
5
0
-5
-10
-15
4
8
12
16
20
24
Extraversion Score
C
Verbal Stroop % RT Conflict
35
30
25
20
15
10
5
0
-5
-10
-15
-4
-2
0
2
4
Approach Factor Score

Figure 2.2.


A
Nonverbal Stroop % RT Conflict
35
30
25
20
15
10
5
0
-5
-10
-15
10
14
18
22
26
30
BIS Score
B
Nonverbal Stroop % RT Conflict
35
30
25
20
15
10
5
0
-5
-10
-15
0
4
8
12
16
20
24
Neuroticism Score
C
Nonverbal Stroop % RT Conflict
35
30
25
20
15
10
5
0
-5
-10
-15
-4
-2
0
2
4
Avoidance Factor Score

CHAPTER 3: COMMON MECHANISMS UNDERLYING LEXICAL AND SYNTACTIC AMBIGUITY RESOLUTION

Abstract

Within the domain of language processing, an important unresolved question is whether the same processing mechanisms are involved in lexical and syntactic ambiguity resolution. The extent to which there is correlated variation in individuals' abilities to resolve lexical and syntactic ambiguities as well as the neurochemical underpinnings of these mechanisms have not yet been investigated. In the current study, subjects were tested on separate syntactic and lexical ambiguity resolution tasks, and they were also genotyped for the val158met polymorphism in the catechol-*O*-methyltransferase (*COMT*) gene, involved in prefrontal cortical dopamine regulation. A significant relationship was found between subjects' ability to resolve ambiguities across both tasks. In particular, those subjects who had more difficulty resolving lexical ambiguities also demonstrated greater difficulty in revising their initial interpretation of syntactically ambiguous sentences. Furthermore, preliminary evidence suggests that variation in a gene related to dopamine regulation in prefrontal cortex is related to both lexical and syntactic ambiguity resolution abilities. These results support constraint-satisfaction models of language processing and suggest that similar processing mechanisms are employed to resolve both lexical and syntactic ambiguities.

Introduction

Ambiguity is prevalent in language processing. Consequently, a great deal of prior research has focused on the mechanisms underlying the resolution of different types of linguistic ambiguities, with a particular focus on lexical and syntactic ambiguities. However, these lines of research have largely progressed in a parallel fashion under the view that lexical and syntactic ambiguities are processed via different mechanisms. In the current study, we provide evidence that challenges this view and suggests commonality in processing of lexical and syntactic ambiguities. Below, we first review the literature on lexical and syntactic ambiguity resolution, as they have been viewed separately, and then discuss theories that propose a framework in which both types of linguistic ambiguities are resolved using the same processing mechanisms.

Several researchers have aimed to determine how and at what point in time contextual information influences lexical ambiguity resolution. Some have supported a modular view of the lexicon, arguing that all meanings of a lexically ambiguous item are automatically activated and that context plays a role in lexical selection only after initial access of multiple meanings (e.g. Conrad, 1974; Lucas, 1987; Onifer & Swinney, 1981; Prather & Swinney, 1988; Swinney, 1979; Tanenhaus, Leiman, & Seidenberg, 1979). An alternative view is that context leads to selective access of only the contextually appropriate meaning (e.g. Glucksberg, Kreuz, & Rho, 1986; Schvaneveldt, Meyer, & Becker, 1976; Simpson, 1981).

The question of when context influences ambiguity resolution has also featured prominently in debates on the nature of syntactic ambiguity resolution. The "garden path" model, a serial depth-first model, has played a dominant role in the field of research on syntactic ambiguity resolution. This model proposes that upon encountering a syntactic ambiguity, a single syntactic structure is considered and that context plays a role in guiding interpretation only later in processing (e.g. Ferriera & Clifton, 1986; Frazier & Clifton, 1997; Frazier & Rayner, 1982). According to these models, only the grammatical structure of the sentence constrains its interpretation initially. If the initial analysis proves to be incompatible with the information available, only then is an alternative interpretation of the sentence constructed, incorporating non-syntactic features (e.g. thematic and discourse) of the input.

The modular nature of serial models, such as the "garden-path model", can be contrasted with interactive models, namely "constraint-satisfaction", or "constraint-based lexicalist", models of language processing. According to these theories, language comprehension functions as an interactive process whereby evidence across several linguistic representational levels, such as phonology, semantics, and syntax, is combined in order to arrive at a single interpretation of the linguistic input (e.g. Gibson & Pearlmutter, 1998; MacDonald, Pearlmutter, & Seidenberg, 1994; Novick, Trueswell, & Thompson-Schill, 2005; Trueswell & Tanenhaus, 1994). Consistent with this framework, some studies of lexical ambiguity resolution have demonstrated that context can serve as a constraint in guiding lexical access (e.g. Duffy, Morris, & Rayner, 1988; Sereno, Brewer, & O'Donnell, 2003; Swaab, Brown, & Hagoort, 2003; Tabossi, 1988) as well as interpretation of syntactically ambiguous sentences early in processing (e.g. Altmann & Steedman, 1988; Crain & Steedman, 1982; Novick, Thompson-Schill, & Trueswell, 2008; St. John & McClelland, 1990; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Trueswell, Sekerina, Hill, & Logrip, 1999; Trueswell & Tanenhaus, 1994; c.f. Clifton et al., 2003; Frazier, 1995; Pickering & Traxler, 1998; van Gompel, Pickering, Pearson, & Liversedge, 2005 for alternative accounts). Under the constraint-satisfaction framework, both lexical and syntactic ambiguities are thought to involve ambiguities concerning lexical representations, where each lexical item is presumed to specify a great deal of syntactic information, such as verb subcategorization and thematic role information. Thus, in contrast to serial models of sentence comprehension, constraint-satisfaction models suggest that lexical and syntactic ambiguities are resolved using the same processing mechanisms.

Another source of evidence for the commonality underlying lexical and syntactic ambiguity resolution stems from the neuroimaging and neuropsychological literatures. Several neuroimaging studies have found greater activation in left ventrolateral prefrontal cortex (lVLPFC), a region implicated in cognitive control (see Miller & Cohen, 2001 for a review), during the resolution of syntactic (e.g. January, Trueswell, & Thompson-Schill, 2009; Mason, Just, Keller, & Carpenter, 2003) and lexical (e.g. Bedny, McGill, & Thompson-Schill, 2008; Rodd, Davis, & Johnsrude, 2005) ambiguities. Furthermore, neural co-localization has been shown for syntactic ambiguity resolution as well as performance on cognitive control tasks, such as the Stroop and flanker tasks (e.g. January et al., 2009; Ye & Zhou, 2009). Critically, neuropsychological studies have also demonstrated that damage to lVLPFC results in processing deficits when resolving lexical (e.g. Bedny, Hulbert, & Thompson-Schill, 2007; Metzler, 2001) and syntactic (e.g. Novick, Kan, Trueswell, & Thompson-Schill, 2009) ambiguities. These results provide intriguing evidence suggesting that cognitive control mechanisms underlie lexical and syntactic ambiguity resolution.

A key thread running through previous investigations of lexical and syntactic ambiguity resolution is that they have been investigated separately. For example, Mendelsohn (2002) showed that individual differences in performance on the Verbal Sorting Task (VST), a linguistic version of the Wisconsin Card Sorting Task, predicted the ability to resolve lexical and syntactic ambiguities in separate experiments, with separate groups of participants. However, in order to more directly test the hypothesis that a common mechanism is used to resolve both lexical and syntactic ambiguities, it is necessary to examine the extent to which individual differences in lexical ambiguity resolution abilities correlate with syntactic ambiguity resolution abilities. An example of such an approach is provided by Novick et al. (2008), who found correlated variation in performance across tasks tapping two different types of syntactic ambiguity: prepositional-phrase attachment ambiguities in one task, and sentence-complement/direct-object ambiguities in the other task. In the current study, we used a similar individual differences approach to investigate whether common processing mechanisms underlie lexical and syntactic ambiguity resolution. Subjects were tested on tasks tapping lexical (homonyms and polysemous words) and syntactic (prepositional-phrase attachment ambiguities) ambiguity resolution abilities. Based on constraint-satisfaction models, we predicted that there would be correlated variation in performance across tasks tapping each of these types of linguistic ambiguities.

A second goal of the current study was to explore the neurobiology of these language processes. The neuroimaging and neuropsychological studies discussed above have shed light on the neural systems underlying lexical and syntactic ambiguity resolution. However, less is known about the neurotransmitter systems underlying these processing mechanisms. The importance of dopamine for prefrontal cortical function and cognitive control has been demonstrated in several studies (e.g. Braver & Barch, 2002; Cohen, Braver, & Brown, 2002; Goldman-Rakic, 1996; Miller & Cohen, 2001). A single nucleotide polymorphism in the gene coding for catechol-*O*-methyltransferase (COMT), an enzyme involved in the catabolism of dopamine, has been linked to individual differences in cognitive control abilities (e.g. Blasi et al., 2005; Bruder et al., 2005; MacDonald, Carter, Flory, Ferrell, & Manuck, 2007; Mattay et al., 2003; see Goldberg & Weinberger, 2004 for a review). The substitution of a single methionine (met) amino acid instead of valine (val) at codon 158 leads to lower levels of COMT activity, resulting in greater availability of dopamine at the synapse (Goldberg & Weinberger, 2004). Individuals homozygous for the val allele tend to have lower availability of dopamine at the synapse. These individuals also tend to demonstrate impaired performance on tasks with cognitive control demands, such as the Wisconsin Card Sorting Task, compared to individuals homozygous for the met allele (e.g. Blasi et al., 2005; Bruder et al., 2005; MacDonald et al., 2007; Mattay et al., 2003, c.f. Ho, Wassink, O'Leary, Sheffield, & Andreasen, 2005; Tsai et al., 2003). Despite the emphasis on variation in the *COMT* val158met polymorphism and its relationship with individual differences in cognitive control abilities, there have been few studies that have investigated how *COMT* variation impacts linguistic ambiguity resolution abilities. Reuter, Montag, Peters, Kocher, & Keifer (2009) recently investigated the role of the *COMT* val158met polymorphism in lexical and semantic processing. Although the authors failed to find a significant association between genetic variation in *COMT* and semantic priming effects, they found that subjects homozygous for the met allele demonstrated faster lexical decision latencies compared to individuals carrying at least one val allele.

Based on this finding and the numerous studies implicating the *COMT* val158met polymorphism in cognitive control abilities, we investigated the role of this polymorphism in both lexical and syntactic ambiguity resolution in the current study. Specifically, we predicted that individuals with the val/val *COMT* genotype would demonstrate exaggerated conflict effects across both the lexical and syntactic ambiguity resolution tasks compared to those individuals with the met/met *COMT* genotype.

Methods

Participants

Seventy-one participants (47 women, 24 men, ages 18-35) participated in this study. Data from nine additional participants were excluded from all analyses for the following reasons: at-chance performance on the lexical ambiguity resolution task (six subjects) and technical difficulties with data collection in the syntactic ambiguity resolution task (three subjects). All subjects were right-handed, native speakers of English, and were not taking any psychoactive medications. The 71 participants comprised the following racial and ethnic backgrounds: 56 Caucasian, 5 African American, 1 Asian, 1 Hispanic, and 8 of mixed race[3]. Subjects were paid at the rate of $10/hour for their participation, and the testing session lasted approximately 1.5 hours. Saliva samples were collected from subjects using Oragene^{TM} collection vials. DNA was extracted using standard procedures and genotyping for the *COMT* val158met polymorphism was performed using an Applied Biosystems TaqMan genotyping assay (see Blasi et al., 2005; Mattay et al., 2003). All subjects gave informed consent prior to participating in the experiment according to guidelines established by the Institutional Review Board of the University of Pennsylvania.

Materials

Syntactic Ambiguity Resolution: Visual World Paradigm

The syntactic ambiguity resolution task used in the current experiment was modeled after the visual word paradigm developed by Tanenhaus et al. (1995) and Trueswell et al. (1999). On each trial, subjects heard a sentence that instructed them to move (using a computer mouse) images of common objects displayed on a monitor (see Farmer, Cargill, Hindy, Dale, & Spivey, 2006; Farmer, Cargill, & Spivey, 2007). Sentences were constructed based on those used by Trueswell et al. (1999). Critical trial-types were either ambiguous (e.g., 1a) or unambiguous sentences (e.g., 1b):

1a) Put the frog on the napkin onto the plate.

1b) Put the frog that's on the napkin onto the plate.

In sentence 1a, the phrase "on the napkin" introduces a temporary prepositional-phrase attachment ambiguity, as it could either indicate a Destination interpretation

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[3] In order to maximize power for the genetic analyses, subjects were not excluded on the basis of race or ethnicity.

(location where the frog should be put), or a Modifier interpretation (which frog should be manipulated). In sentence 1b, the inclusion of "that's" removes this temporary ambiguity by forcing a Modifier interpretation. Critical trials were presented in only a one-referent context (e.g., only one frog) as this context induces the "garden-path" effect (see Tanenhaus et al., 1995; Trueswell et al., 1999).

Both ambiguous and unambiguous sentences began with the verb "put". In order to obscure the experimental manipulation, we included 32 filler trials: of these, 16 began with the verb "put" (e.g. "Put the horse on the cookie sheet") in order to avoid having "put" signal the start of critical trial-types. The remaining 16 filler trials began with non-"put" verbs (e.g. "Slide the walrus onto the newspaper"). Each subject heard either the ambiguous or unambiguous version of a critical trial, counterbalanced across subjects. Two trial orders were also counterbalanced across subjects.

At the start of each trial, an object appeared in each quadrant of the screen along with auditorily presented labels (spoken by a male) via pre-recorded sound files for each object. Subjects were then instructed to look at a fixation cross located at the center of the screen. Upon doing so, a black box surrounding the fixation cross turned green. Subjects mouse-clicked on the fixation cross to start the trial. Upon clicking the fixation cross, a pre-recorded sound file with auditory instructions (spoken by a female) played over speakers. For a sentence such as 1a or 1b, the visual display comprised a frog sitting on a napkin, a horse, a plate, and an empty napkin, each in a separate quadrant of the screen. Subjects were instructed to carry out the instructions that they heard by using a computer mouse. In all trials (both critical and filler trial-types), subjects had to move a target object to a particular location. Upon completing the instructed action, subjects pressed the spacebar in order to start the next trial.

Subjects completed a total of 48 trials comprising the following numbers of each trial-type: 8 ambiguous, 8 unambiguous, and 32 filler trials.[4] Subjects also completed a practice block of 10 trials prior to starting the experimental blocks in order to familiarize them with the task procedure. None of the stimuli used in the experimental blocks, nor any trials resembling ambiguous or unambiguous trials, was presented during the practice block. Subjects' eye movements were measured—from the onset of the trial until the end of the action—using a Tobii 1750 eye-tracker; we calibrated the eye tracker immediately before beginning this task. The task lasted approximately ten minutes.

Lexical Ambiguity Resolution: Relatedness Judgment Task

The relatedness judgment task was modeled directly after the procedure used by Bedny et al. (2008). Trial and stimuli design are described briefly below, but we refer the interested reader to Bedny et al. (2008) for additional details about this paradigm.

Subjects viewed pairs of words and indicated whether the two words were related to each other in meaning. As in Bedny et al. (2008), subjects were instructed that "related" referred to two words that were either similar in meaning (e.g. "cat" and "dog") or to two words that were associated in meaning (e.g. "dog" and "leash"). Subjects were

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[4] Subjects also completed a second block of 48 trials of the syntactic task (with the same number of ambiguous, unambiguous, and filler trials as in the first block). A second block of trials was included in an attempt to increase our power to assess syntactic conflict effects. However, an examination of overall reaction times for ambiguous and unambiguous trials (i.e. the time to complete the trial) revealed a significant reaction time conflict effect (longer RT for ambiguous compared to unambiguous trials) for the first block, but not for the second block. Thus, it appears that subjects demonstrated learning during the second block of the task. In light of this result, and the fact that including the second block increases the number of critical trials well beyond the standard number included in similar studies (e.g. Novick et al., 2008; Trueswell et al., 1999), only data from the first block are presented in the current study.

instructed to press a key marked “yes” with their right index finger to indicate that the words were related to each other, or a key marked “no” with their left index finger to indicate that the words were not related to each other. Subjects were given 3000 ms to make each judgment, and subjects were instructed to respond as quickly and as accurately as possible. We use the term “trial” to refer to two consecutive pairs, followed by an inter-trial-interval (ITI) of 3000 ms (a black screen with four white fixation crosses); the first pair served as a prime for the second (target) pair on each trial.

There were two critical trial-types of interest: consistent and inconsistent trials. For both of these trial-types, the second word of each pair was a lexically ambiguous word[5]. For consistent trials, the first words of each word pair referenced the same meaning of the lexically ambiguous word (e.g. GOLD-BAR, SOAP-BAR). For inconsistent trials, the first words of each word pair referenced different meanings of the lexically ambiguous word (e.g. SMOKE-BAR, SOAP-BAR). Thus, both consistent and inconsistent trials contained lexically ambiguous words; however, in the consistent trials, the prime pair facilitates ambiguity resolution for the target pair. Each subject saw either the consistent or inconsistent version of a critical trial, counterbalanced across subjects. For both the prime (first pair) and target (second pair) word pairs, approximately half referred to the dominant meaning of the lexically ambiguous word and the other half referred to the subordinate meaning.

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[5] Some of the ambiguous words were homonyms (e.g., bank); others were polysemous (e.g., chicken). As Bedny et al. (2008) did not find any behavioral or neural differences between these two types of lexical ambiguities, and as the distinction between them does not constitute the focus of the current study, both homonyms and polysemous words will be referred to as lexically ambiguous words. Additionally, all reported analyses collapse across trials with homonyms and polysemous words.

The majority of trials were control trials and filler trials: For control trials, words within each word pair were related to each other; however the two word pairs in each trial were not related to each other (e.g. COLONEL-LIEUTENANT, FROST-SNOW). Control trials did not include lexically ambiguous words. Filler trials were also included in order to obscure the task manipulation. Filler trials comprised the following three trial-types: two pairs of unrelated words, related words in the first pair and unrelated words in the second pair, and unrelated words in the first pair and related words in the second pair. Of the 112 filler trials, 41 included a repeated word, and 63 included a lexically ambiguous word.

Subjects completed a total of 224 trials: 37 consistent, 37 inconsistent, 38 control, and 112 filler trials. Trials were divided into five separate blocks, consisting of approximately 44 trials per block. Subjects also completed a practice block of 46 trials prior to starting the experimental blocks in order to familiarize them with the task procedure. None of the stimuli used in the experimental blocks was presented during the practice block. Trials were presented in a fixed, pseudorandomized design, and the task took approximately 40 minutes to complete. Stimuli were presented and responses were collected using E-prime software.

Procedure

Subjects completed the syntactic ambiguity resolution task followed by the lexical ambiguity resolution task[6]. Tasks were administered to all subjects in the same order in

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[6] These subjects were from the same population of subjects who completed the verbal and nonverbal Stroop tasks as well as the personality assessments described in Chapter 2. The measures described in Chapters 2 and 3 were collected in separate testing sessions. The relationships between subjects' performance on the

order to minimize measurement error due to participant x task order interactions (e.g. Friedman & Miyake, 2004; Friedman et al., 2008; Miyake et al., 2000). Saliva samples were collected for genotyping purposes at the conclusion of the testing session.

Data Analysis Procedures

For the syntactic ambiguity resolution task, the coordinates of each object in the video monitor display were used by the eye-tracker system to automatically code participants' eye movements. Samples indicating subjects' direction of eye gaze were obtained every 20 ms. As in Novick et al. (2008), trials in which more than 33 % of the samples were lost due to track-loss were excluded from all analyses. The primary measure of interest was the proportion of time spent looking at the incorrect goal from the onset of the word denoting the incorrect goal in the auditory instruction (e.g. "napkin" in the example above) until the action was completed for both ambiguous and unambiguous trials. This window was offset by 200 ms in order to allow for the time lag between programming an eye movement and initiating that eye movement (Matin, Shao, & Boff, 1993). As an additional measure of interest, the percentage of trials in which a look was made to the incorrect goal was calculated from the onset of the word indicating the incorrect goal (e.g. "napkin", offset by 200 ms).

As in Bedny et al. (2008), the primary behavioral measures of interest for the lexical ambiguity resolution task were the latency and accuracy of the relatedness judgments for the second (target) word pair of consistent and inconsistent trials. In order to ensure that subjects were responding to the second word pair after having been

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lexical, syntactic, verbal Stroop, and nonverbal Stroop tasks, as well as the relationship between genetic variation and individual differences in Stroop performance will be discussed in the General Discussion.

"primed" successfully with the first word pair, trials in which subjects incorrectly responded "No" to the first word pair were excluded from all analyses.

Results

Syntactic Ambiguity Resolution: Visual World Paradigm

Means of the proportion of time spent looking at the incorrect goal (offset by 200 ms from the onset of "napkin" until the end of the trial), percentage of trials with looks to the incorrect goal, and split-half reliabilities are presented in Table 3.1.

As predicted, subjects spent a greater proportion of time looking at the incorrect goal on ambiguous compared to unambiguous trials ($t[70] = 4.32$, $p < 0.001$)[7]. A significant difference in the proportion of time spent looking at the incorrect goal was also found at the item-level ($t[15] = 3.57$, $p < 0.01$). Subjects also demonstrated a higher percentage of trials with looks to the incorrect goal for the ambiguous compared to the unambiguous condition ($t[70] = 4.40$, $p < 0.001$).

Lexical Ambiguity Resolution: Relatedness Judgment Task

Means of median reaction times (for correct trials), percent error rates, and split-half reliabilities are presented in Table 3.2; all of the reported reaction time and percent error rates are for the second word pair of each trial. Results were very similar to those reported by Bedny et al. (2008): subjects were faster ($t[70] = 10.18$, $p < 0.001$) and more accurate ($t[70] = 9.23$, $p < 0.001$) on consistent compared to inconsistent trials.

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[7] All behavioral analyses involving the proportion time measure for the syntactic task were also performed using the following arcsin transformation: arcsin ((2 * proportion)-1). The arcsin transformation is used to adjust for the bounding of proportions between 0 and 1. The analyses performed on transformed data yielded a similar pattern of results as the analyses performed on untransformed data.

Individual Differences in Syntactic and Lexical Ambiguity Resolution

Having demonstrated that subjects exhibit conflict effects (i.e. greater difficulty for inconsistent/ambiguous trials compared to consistent/unambiguous trials) for both the lexical and syntactic tasks, we next investigated whether there was correlated variation in conflict resolution abilities across the two tasks. The split-half reliabilities were higher for ambiguous and unambiguous trial-types in the syntactic ambiguity resolution task (see Table 3.1) than for the difference score (ambiguous – unambiguous) (Spearman-Brown split-half reliability coefficient = 0.28). Similarly, the split-half reliabilities were high for reaction times on consistent and inconsistent trials in the lexical ambiguity resolution task (see Table 3.2); however, the reliability for the difference score (inconsistent RT – consistent RT) was rather low (Spearman-Brown split-half reliability coefficient = 0.37). Several researchers have noted the unreliability of difference scores (e.g. Cronbach & Furby, 1970; Edwards, 1994). Thus, rather than using difference scores as measures of lexical and syntactic conflict in our correlational analyses, we adopted a regression approach that involves calculating residual change scores (see Edwards, 1994; Friedman & Miyake, 2004). Furthermore, as the difference score in reaction times can become larger as subjects' overall speed increases, employing a regression approach allowed us to account for overall processing speed (see also Wager, Jonides, & Smith, 2006 for a similar approach). Across subjects, median response times for the inconsistent trials of the lexical ambiguity resolution task were regressed on median response times for the consistent trials; the residuals from this regression were then used as the measure of lexical conflict for each subject and will be referred to as residual conflict scores. The same approach was used for the syntactic ambiguity resolution task, where the measures of performance were the proportion of time spent looking at the incorrect goal for ambiguous and unambiguous trials. Correlations were then calculated between subjects' residual conflict scores for the lexical and syntactic tasks. The split-half reliabilities for the syntactic and lexical residual conflict scores were higher (see Tables 3.1 and 3.2) than for the difference scores reported above.

A significant correlation was found between residual conflict scores for lexical and syntactic tasks (Pearson $r = 0.235$, $p < 0.05$; Spearman's rho = 0.27, $p < 0.05$) (Figure 3.1). The finding of correlated variation in performance across lexical and syntactic ambiguity resolution tasks suggests that common mechanisms may be involved in resolving both of these types of linguistic ambiguities.

The correlational analysis between lexical and syntactic residual conflict scores does not address the possibility that non-specific factors, such as general ability or arousal, may underlie the correlation between lexical and syntactic conflict scores. In order to determine the specificity of the relationship between performance on the lexical and syntactic ambiguity resolution tasks, we investigated the correlations between lexical and syntactic trial-types separately, using the lexical consistent and syntactic unambiguous trials as "negative controls". Under the constraint-satisfaction account, one would expect a correlation between performance on the syntactic ambiguous and lexical inconsistent trials, but not between the syntactic unambiguous and lexical consistent trials. That is, the syntactic ambiguous and lexical inconsistent trials are the trials in which a common conflict resolution mechanism might be recruited. As predicted, we found that subjects' proportion of time spent looking at the incorrect goal on ambiguous trials in the syntactic task was correlated with their reaction times for inconsistent trials in the lexical task (Pearson $r = 0.30$, $p < 0.05$; Spearman's rho = 0.20, $p = 0.09$) (Figure 3.2 A). However, subjects' proportion of time spent looking at the incorrect goal for unambiguous trials in the syntactic task was not significantly correlated with their reaction times for consistent trials in the lexical task (Pearson $r = -0.16$, $p = 0.18$; Spearman's rho = -0.11, $p = 0.36$) (Figure 3.2 B). Additionally, the strength of these correlations ($r = 0.30$ vs. $r = -.16$) was significantly different ($z = 3.38$, $p < 0.001$).

We also investigated whether the difference between ambiguous and unambiguous syntactic trials in terms of the percentage of trials with looks to the incorrect goal (instead of proportion of time on each trial) would be correlated with the lexical residual conflict effect. Although this relationship was not significant (Pearson $r = 0.14$, p = 0.24; Spearman's rho = 0.17, p = 0.16), it suggested a positive relationship between these measures. We also calculated correlations separately between syntactic ambiguous and lexical inconsistent trials, and also between syntactic unambiguous and lexical consistent trials, for these measures. A significant correlation was found between the percentage of ambiguous trials in which subjects made a look to the incorrect goal in the syntactic task and their reaction times for inconsistent trials in the lexical task (Pearson $r = 0.29$, $p < 0.05$; Spearman's rho = 0.22, $p = 0.06$) (Figure 3.3 A). However, the correlation between these measures was not significant for syntactic unambiguous and lexical consistent trials (Pearson $r = -0.11$, $p = 0.37$; Spearman's rho = -0.07, $p =$

0.59) (Figure 3.3 B). Additionally, the strength of the correlations ($r = 0.29$ vs. $r = -0.11$) was significantly different ($z = 3.26$, $p < 0.01$).

Genetic Contributions to Individual Differences in Ambiguity Resolution

Data from two subjects were excluded from all genetic analyses due to inability to obtain a genotype. This left a total of 69 subjects for the genetic analyses. Subjects' syntactic residual conflict scores were submitted to a one-way ANOVA to test for differences in the magnitude of syntactic conflict effects across the *COMT* genotype groups. The results of this analysis revealed a significant difference in syntactic conflict effects across *COMT* genotype groups ($F[2,66] = 3.17$, $p < 0.05$). However, as Levene's test indicated that the assumption of homogeneity of variance across the genotype groups was violated ($F[2,66] = 8.42$, $p < 0.01$), we also report the Brown-Forsythe ($F[2, 28.1] = 2.66$, $p = 0.088$) and Welch tests ($F[2, 32] = 2.08$, $p = 0.14$), which do not assume homogeneity of variance. Based on these trends, Games-Howell post-hoc tests, which do not assume homogeneity of variance, were conducted. Although not statistically significant, the val/val genotype group tended to have higher syntactic residual conflict scores compared to both the met/met genotype group ($p = 0.13$) and the val/met genotype group ($p = 0.28$) (see Table 3.3).

The one-way ANOVA for lexical residual conflict scores did not yield a significant effect of genotype, suggesting that the *COMT* genotype groups were not differentially associated with the magnitude of lexical conflict ($F < 1$). However, given that both the consistent and inconsistent trials involve lexically ambiguous words, we performed an exploratory analysis to investigate whether *COMT* val158met genotype was associated with performance across both consistent and inconsistent trials of the lexical task. Subjects' reaction times for consistent, inconsistent, control, and filler trials were submitted to a repeated-measures mixed ANOVA with lexical task condition (consistent, inconsistent, control, filler) as a within-subjects factor and *COMT* val158met genotype as a between-subjects factor. Mauchly's test indicated that the assumption of sphericity was violated ($\chi^2(5) = 32.9$, $p < 0.001$). Accordingly, the Greenhouse-Geisser estimate of sphericity ($\varepsilon = 0.76$) was used to correct the degrees of freedom. A significant condition x genotype interaction effect was found, due to a differential effect of *COMT* genotype on the response times for the different lexical task conditions ($F[4.53, 149.43] = 2.63$, $p < 0.05$). This result indicates specificity in the association between *COMT* genotype and response times across the lexical task conditions. In order to investigate whether *COMT* genotype impacted both consistent and inconsistent trials, a repeated-measures mixed ANOVA was performed with task condition (consistent, inconsistent) as a within-subjects factor and *COMT* genotype as a between-subjects factor. A main effect of *COMT* genotype was found, indicating a significant difference in performance between the genotype groups across both consistent and inconsistent trials ($F[2,66] = 3.87$, $p < 0.05$). No significant condition x genotype interaction effect was found ($F < 1$). Post-hoc Tukey's HSD tests revealed that the val/val genotype group had significantly slower reaction times across both consistent and inconsistent trials compared to the val/met genotype group ($p < 0.05$) (see Table 3.4). All other pairwise comparisons were not significant (p's > 0.25).

A repeated-measures mixed ANOVA for response times on the control and filler trials failed to reveal a significant main effect of genotype nor a condition x genotype interaction effect (*F*'s < 1). These results demonstrate the specificity of the association between *COMT* genotype and reaction times on the different conditions of the lexical ambiguity resolution task. In particular, the val/val subjects did not demonstrate slower reaction times across all conditions. Rather, their performance was impaired only on those trials involving processing of lexical ambiguities[8].

Discussion

A key prediction of constraint-satisfaction models of language processing is that lexical and syntactic ambiguities are resolved using the same mechanisms (MacDonald et al., 1994; Trueswell & Tanenhaus, 1994). In contrast, serial models propose that lexical and syntactic ambiguities are resolved via separate processing mechanisms (see Frazier, 1995).

In the current study, we found a significant correlation between lexical and syntactic ambiguity resolution abilities. Moreover, further investigation of this result demonstrated the specificity of the correlation. In particular, a significant correlation was found for performance across lexical inconsistent and syntactic ambiguous trials. Additionally, this correlation was significantly stronger than the correlation for

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[8] In light of these results, we calculated separate correlations between subjects' syntactic residual conflict scores and their reaction times for inconsistent and consistent trials. Significant correlations were found between syntactic conflict and reaction times for inconsistent trials (Pearson $r = 0.39$, $p < 0.01$; Spearman's rho = 0.22, $p = 0.06$) as well as reaction times for consistent trials (Pearson $r = 0.31$, $p < 0.01$; Spearman's rho = 0.15, $p = 0.21$). Thus, lexical consistent trials may invoke some conflict, although not as much as in lexical inconsistent trials.

performance across lexical consistent and syntactic unambiguous trials. This finding mitigates the concern that the correlation across the lexical and syntactic ambiguity resolution tasks was due to non-specific factors, such as general ability. If this had been the case, we would have also found a significant correlation across lexical consistent and syntactic unambiguous trials. However, this correlation was not significant.

These results provide support for constraint-satisfaction models of language processing by demonstrating that lexical and syntactic ambiguity resolution abilities rely on similar processing mechanisms. The correlation between ambiguity resolution abilities across these two tasks would not be predicted by serial models of language processing and thus serve as a means of distinguishing these two classes of models. Although proponents of serial models may characterize this correlation as reflecting the relationship between post-syntactic and post-lexical processes, eye movement measures reflect early processes that are unlikely to be post-syntactic in nature. One potential criticism of the current set of results concerns the magnitude of the observed correlation (a Pearson *r* value of 0.235) between lexical and syntactic ambiguity resolution abilities. At first blush, explaining 5-6 % percent of the variance in the conflict effects across these two tasks may seem unimpressive. However, it is useful to place an upper bound on how high of a magnitude we might expect for the correlation between lexical and syntactic conflict effects. One source of such an upper bound stems from Novick et al.'s (2008) study, which employed two types of syntactic ambiguities: prepositional-phrase attachment ambiguities, assessed via the visual world paradigm, as well as direct-object/sentence-complement ambiguities, assessed via a reading task. Novick et al.

(2008) reported a Pearson *r* value of 0.52 for the correlation between ambiguity resolution abilities across these two tasks. Although the magnitude of the correlation reported in the current study is smaller than this value, it is important to note that we would not have expected a Pearson *r* value greater than 0.52. Furthermore, a calculation of the 95 % confidence interval for this correlation with Novick et al's sample size of 40 participants yielded the following range of values: 0.25 to 0.72. Thus, although not within this range, our finding of a correlation of 0.235 is reasonably close to the lower bound of this confidence interval. The split-half reliability estimates of lexical and syntactic residual conflict scores can be used as another source of the upper bound for the expected magnitude of the correlation between these conflict scores. Based on the rather low split-half reliabilities reported in Tables 3.1 and 3.2, the magnitude of the correlation between lexical and syntactic conflict scores would not be expected to be higher than these values.

In addition, we would like to emphasize the number of differences that exist between the two tasks employed in the current study. In the syntactic ambiguity resolution task, subjects' eye movements were monitored as they carried out auditory instructions by moving objects using a computer mouse. In the lexical ambiguity resolution task, these subjects were instructed to indicate the relatedness of word pairs, and the primary measure of interest was their reaction time to do so. Our finding of a significant correlation between measures as disparate as eye movements and button press reaction times provides a strong test of the constraint-satisfaction hypothesis. Although a stronger correlation may have been obtained had we utilized reaction time measures for both the syntactic and lexical ambiguity resolution tasks, this may have resulted from more superficial similarities between the tasks. Thus, by using two very different tasks, our finding of correlated variation in performance across these tasks is all the more intriguing. Our results thus build upon the results reported by Novick et al. (2008), as we have shown that their finding can be extended to lexical ambiguity resolution tasks where subjects are assessing the relationship between single words. Further research is necessary in order to investigate the extent to which different types of lexical and syntactic ambiguities rely on shared processing mechanisms. The current study used the prepositional phrase attachment ambiguity as an example of a syntactic ambiguity and both homonyms and polysemous words as examples of lexical ambiguities. Future studies should explore whether the finding of the current study extends to other types of linguistic ambiguities, such as reduced relatives as well as quantifier and scope ambiguities.

An additional novel feature of the current study involves the investigation of the neurotransmitter systems underlying linguistic ambiguity resolution abilities. The results of the current study indicate that variation in a gene that regulates dopamine levels in prefrontal cortex is related to linguistic ambiguity resolution abilities. Those subjects with the variant of the *COMT* val158met polymorphism associated with lower levels of prefrontal cortical dopamine (val/val genotype group) tended to demonstrate larger conflict effects on the syntactic ambiguity resolution task relative to the other genotype groups. Although the magnitude of lexical conflict did not significantly differ between the *COMT* genotype groups, an exploratory analysis revealed that subjects with the val/val genotype demonstrated longer reaction times for both consistent and inconsistent trials in the lexical ambiguity resolution task. As both consistent and inconsistent trials involve lexically ambiguous words, this finding may indicate that subjects with the val/val genotype have greater difficulty with processing ambiguities, perhaps in addition to difficulty with resolving linguistic conflict. These results are consistent with those of Reuter et al. (2009), who found that subjects with the val/val genotype demonstrated longer lexical decision latencies compared to other *COMT* genotype groups. However, the current set of results extends this finding to show that genetic variation in *COMT* also appears to be associated with linguistic ambiguity resolution abilities. We note that the behavioral genetic findings reported in the current study were not statistically robust and only indicate trends. Nonetheless, these findings are intriguing in nature and constitute preliminary novel evidence suggesting commonality between linguistic ambiguity resolution and cognitive control mechanisms at the neurotransmitter level. Furthermore, these results serve to bridge the literatures on linguistic ambiguity resolution with the extensive literature on the role of dopamine in cognitive control abilities.

In conclusion, the current study provides support for constraint-satisfaction models of language processing. Using an individual differences approach, we have shown that individuals' ability to resolve lexical ambiguities is related to their ability to resolve syntactic ambiguities. As an extension of the current study, it would be interesting to investigate whether neural co-localization would be found in lVLPFC within subjects performing both the lexical and syntactic ambiguity resolution tasks. Based on the current set of results as well as previous studies, one would predict that this result would be obtained. Additionally, it would be interesting to investigate whether variation in the *COMT* genotype would be associated with the extent of lVLPFC activation during resolution of both lexical and syntactic ambiguities. The combination of different methodologies holds great promise for elucidating our understanding of the processing mechanisms underlying ambiguity resolution across different domains of cognition. The results of the current study demonstrate an example of such an approach.

Table 3.1. *Performance Summary for Syntactic Ambiguity Resolution Task.*

Syntactic Trial-Type	**Mean Proportion of Time**	***SD***	**Reliability**	**Mean % Trials**	***SD***
Ambiguous	0.033	0.028	0.42	36.2	23.4
Unambiguous	0.019	0.019	0.62	25.2	21.7
Ambiguous - Unambiguous	0.014	0.027	0.34[a]	11.1	21.2

Note. Syntactic Trial-Type, each trial-type in the visual world paradigm as well as the (Ambiguous-Unambiguous) difference score; Mean Proportion of Time, mean proportion of time spent looking at the incorrect goal from the onset of the word denoting the incorrect goal (e.g. "napkin", offset by 200 ms) until the end of the trial; Reliability, split-half reliability (odd-even) adjusted with the Spearman-Brown prophecy formula. *SD* corresponds to standard deviation. *N* = 71 for all measures.

[a] Split-half reliability is reported for the residual conflict score (reliability coefficient for difference score reported in the main text).

Table 3.2. *Performance Summary for Lexical Ambiguity Resolution Task.*

Lexical Trial-Type	**Mean RT**	***SD***	**Mean Percent Error**	***SD***	**Reliability**
Consistent	1008	165	20.3	13.3	0.87
Inconsistent	1154	204	30.7	16.1	0.81
Inconsistent - Consistent	146	121	10.5	10.5	0.42[a]
Control	1141	134	7	5.6	
Filler	1233	132	6.5	2.8	

Note. Lexical Trial-Type, each trial-type in the relatedness judgment task as well as the (Inconsistent-Consistent) RT difference score; Reliability, split-half reliability (odd-even) for critical trials adjusted with the Spearman-Brown prophecy formula. *SD* corresponds to standard deviation. *N* = 71 for all measures.

[a] Split-half reliability is reported for the residual conflict score (reliability coefficient for difference score reported in the main text).

Table 3.3. *Syntactic Conflict Effects for COMT val158met Genotype Groups*.

COMT val158met Genotype Group	**Mean Syntactic Residual Conflict Score**	***SD***
val/val (n = 16)	0.013	0.038
val/met (n = 35)	-0.002	0.022
met/met (n = 18)	-0.007	0.016

Note. *SD* corresponds to standard deviation.

Table 3.4. *Performance of COMT val158met Genotype Groups on Lexical Ambiguity Resolution Task (critical trials).*

COMT val158met Genotype Group	**Mean Consistent RT**	***SD***	**Mean Inconsistent RT**	***SD***
val/val (n = 16)	1089	199	1243	253
val/met (n = 35)	960	144	1103	187
met/met (n = 18)	1035	137	1183	152

Note. RTs correspond to mean of median reaction times. *SD* corresponds to standard deviation.

Figure Captions

Figure 3.1. Correlation between residual conflict scores for syntactic and lexical ambiguity resolution tasks. Corresponding Pearson *r* and Spearman's rho coefficients provided in main text.

Figure 3.2. Correlations between syntactic trials (proportion of time spent looking at the incorrect goal from the onset of "napkin") and lexical trials (median RT in milliseconds) for (A) Syntactic ambiguous trials and lexical inconsistent trials and (B) Syntactic unambiguous trials and lexical consistent trials. Corresponding Pearson *r* and Spearman's rho coefficients provided in main text.

Figure 3.3. Correlations between syntactic trials (% trials with looks to the incorrect goal from the onset of "napkin") and lexical trials (median RT in milliseconds) for (A) Syntactic ambiguous trials and lexical inconsistent trials and (B) Syntactic unambiguous trials and lexical consistent trials. Corresponding Pearson *r* and Spearman's rho coefficients provided in main text.

Figure 3.1.

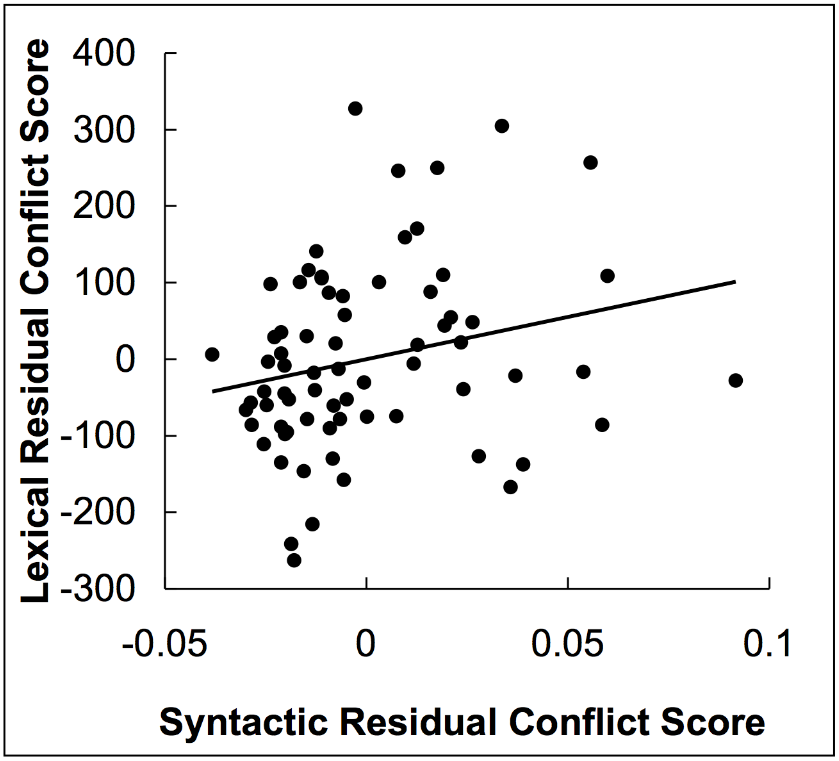

Lexical Residual Conflict Score
400
300
200
100
0
-100
-200
-300
-0.05
0
0.05
0.1
Syntactic Residual Conflict Score

Figure 3.2.

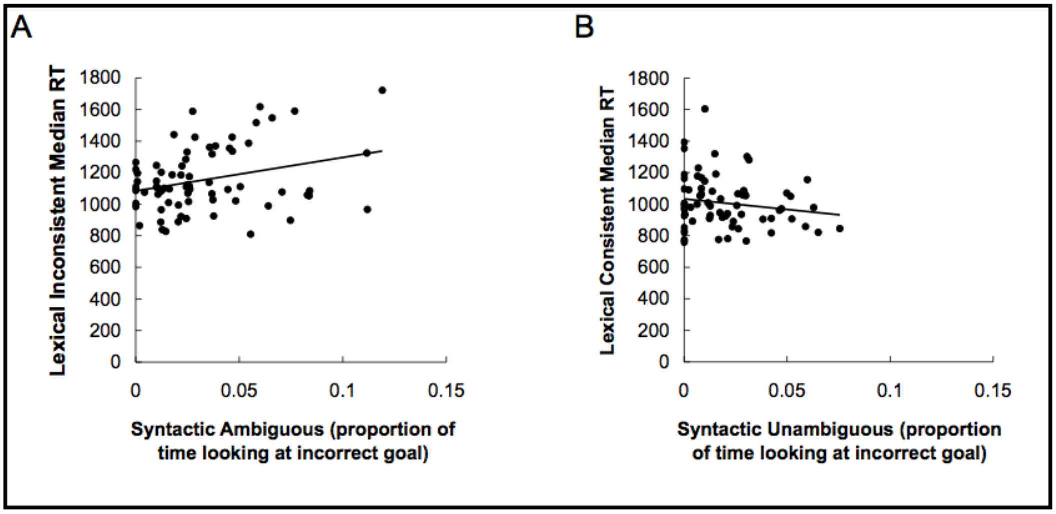
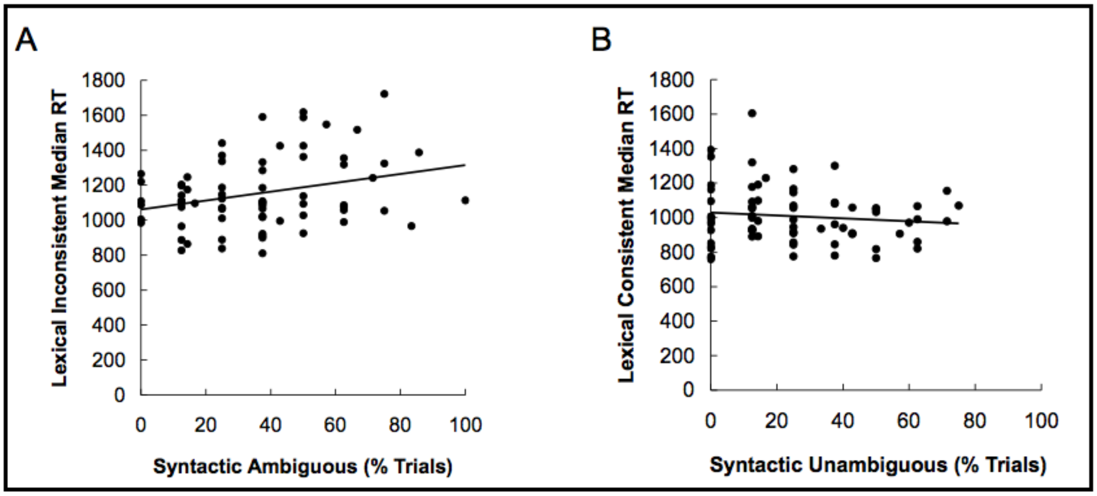

A
Lexical Inconsistent Median RT
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.05
0.1
0.15
Syntactic Ambiguous (proportion of time looking at incorrect goal)
B
Lexical Consistent Median RT
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.05
0.1
0.15
Syntactic Unambiguous (proportion of time looking at incorrect goal)

Figure 3.3.


A
Lexical Inconsistent Median RT
1800
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
Syntactic Ambiguous (% Trials)
B
Lexical Consistent Median RT
1800
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
Syntactic Unambiguous (% Trials)

CHAPTER 4: GENERAL DISCUSSION

What are the factors that influence our ability to modulate behavior in a context-dependent fashion? The answer to this question is undoubtedly complex and multifaceted in nature. In the studies described in Chapters 2 and 3, we demonstrate how the use of an individual-differences approach reveals a few facets of this answer. By viewing human behavior through the lens of variation in personality traits, cognitive control, and linguistic ambiguity resolution abilities, we were able to demonstrate the following findings. In Chapter 2, we showed that individual differences in the personality traits of approach and avoidance are associated with variability in verbal and nonverbal cognitive control abilities, respectively. These results highlight the differences between cognitive control abilities in the verbal and nonverbal domains. In Chapter 3, we demonstrated how an individual-differences approach can reveal the commonality between processing mechanisms. Within the domain of language processing, we showed correlated variation in lexical and syntactic ambiguity resolution abilities. Furthermore, through the use of behavioral genetics techniques, we have illustrated how variation at the genetic level can be used to elucidate our understanding of individual differences in ambiguity resolution abilities. Specifically, we showed that variation in a gene related to the regulation of dopamine in prefrontal cortex was associated with the ability to process both lexical and syntactic ambiguities. Below, we discuss the implications of each of these findings in greater detail.

Individual Differences in Personality & Cognitive Control

In Chapter 2, we focused on the domain-specific aspects of cognitive control abilities. In discussing the need for future work to investigate the relationship between approach/avoidance and specific cognitive control abilities, Gray (2001) noted that if in fact both cognitive control and approach/avoidance sensitivities are organized in a hemisphere-specific fashion, "The most simple prediction of the current account is that cognitive control functions that show hemispheric specialization in PFC will also show selective modulation by approach and withdrawal states" (p. 448). Our results are partially consistent with this prediction. In particular, we found that the overlap across the Behavioral Activation System (BAS) and Extraversion, or approach sensitivity, predicted performance on the verbal Stroop task, whereas the overlap across the Behavioral Inhibition System (BIS) and Neuroticism, or avoidance sensitivity, predicted performance on the nonverbal Stroop task.

It is important to note that although approach sensitivity predicted verbal, but not nonverbal, Stroop conflict effects, we did not find a significant difference between the strength of these correlations. Similarly, although avoidance sensitivity predicted nonverbal, but not verbal, Stroop conflict effects, no significant difference was found in the strength of these correlations. As a result, we are unable to make a strong claim regarding the interaction of personality and cognitive control in a domain-specific manner. Nonetheless, given the prior literature on the differential roles of the right and left prefrontal cortex for verbal/nonverbal cognitive control and approach/avoidance sensitivities, our results are suggestive of a hemisphere-specific association between motivational personality traits and cognitive control abilities. Thus, the correlation between approach and verbal Stroop performance may reflect the reliance of both of these systems on left prefrontal cortex, and the association between avoidance and non-verbal Stroop may reflect the fact that both are subserved by right prefrontal cortex.

What implications do these findings have for the organization of cognitive control processing mechanisms? As Gray (2001) speculated, one possibility is that the association between verbal cognitive control and approach could represent merely "an uninteresting consequence of co-lateralization" (p. 448). Gray (2001) also suggested the possibility that these hemisphere-congruent associations may reflect the differential distribution of neurochemical pathways across the left and right hemispheres. Whereas dopamine pathways tend to be more heavily concentrated in the left hemisphere, norepinephrine pathways are more right-lateralized (see Tucker & Williamson, 1984 for a review). Furthermore, dopaminergic and norepinephrine systems in prefrontal cortex have been shown to be mutually inhibitory (Tassin, 1998). Thus, it is possible that the incompatible motivational systems of approach and avoidance are segregated on a hemispheric basis, with differential reliance on dopaminergic and norephinephrine neurotransmistter systems (see Depue & Collins, 1999; Gray & McNaughton, 2000). Similarly, the hemispheric specialization for verbal and nonverbal cognitive control may stem from their differential reliance on dopaminergic and norepinephrine systems. For example, previous studies have shown that norepinephrine plays a larger role in spatial working memory abilities compared to dopamine (e.g. Rossetti & Carboni, 2005; Tucker & Williamson, 1984).

In sum, the use of an individual-differences approach allowed us to uncover a source of variation in performance on one of the most commonly used tests of cognitive control ability: the Stroop task. Furthermore, we were able to demonstrate relationships between personality and a specific cognitive control ability (response inhibition) in an unselected, cognitively unimpaired population; a population that serves as the focus in the majority of experimental psychology studies. Thus, we have shown that variability in cognitive control performance, which may be considered as noise by some researchers, is significantly correlated with variation in personality traits. This finding carries important implications for all studies that employ laboratory tests of cognitive control and uncovers a source of variability in task performance that is related to personality trait characteristics.

Individual Differences in Ambiguity Resolution Abilities

In Chapter 3, we used an individual-differences approach to investigate commonality in processing mechanisms within the domain of language processing. In particular, we provided a critical test of constraint-satisfaction theories by investigating whether variation in lexical ambiguity resolution abilities is related to variation in syntactic ambiguity resolution abilities. Inherent in MacDonald, Pearlmutter, & Seidenberg's (1994) claim that syntactic ambiguities are ambiguities at the lexical level, is the prediction that individual differences in ambiguity resolution should be related across lexical and syntactic tasks.

The results of Chapter 3 demonstrated correlated variation in lexical and syntactic ambiguity resolution abilities. Thus, our results appear to provide support for MacDonald et al.'s (1994) assertion that across the domains of lexical and syntactic processing, "the same ambiguity resolution mechanisms apply in both domains because both involve ambiguities over various types of lexical representations" (p. 682). Furthermore, it is important to note that our findings provide a strong test of constraint-satisfaction theories by demonstrating correlated variation in performance across two tasks that differ across a variety of characteristics, such as the measures of processing difficulty (reaction times vs. eye movements) and type of stimuli (visually presented word pairs vs. auditorily presented sentences).

MacDonald et al. (1994) also propose that "whereas there may be distinctly linguistic forms of *representation*, the *processing* principles that account for language comprehension and ambiguity resolution are not specific to language at all" (p. 700). As the same subjects completed the tasks described in Chapters 2 and 3, we were able to test this proposal. Indeed, we selected the verbal Stroop, nonverbal Stroop, and the lexical and syntactic ambiguity resolution tasks on the basis of previous neuroimaging (e.g. Bedny et al., 2008; January et al., 2009; Ye & Zhou, 2009), and neuropsychological (e.g. Novick et al., 2009) studies suggesting that these tasks may all rely on more general cognitive control processing abilities. However, despite the promising evidence suggesting links between linguistic ambiguity resolution and more general cognitive control abilities, we did not observe significant correlations between individual differences in the lexical and syntactic ambiguity resolution tasks and performance on the verbal and nonverbal Stroop tasks described in Chapter 2. The failure to find significant correlations with these standard measures of cognitive control is rather surprising. However, we can offer a few potential explanations for these null results. One explanation stems from the separate sessions (on separate days) in which subjects were tested on the lexical and syntactic tasks (Session 1) and the verbal and nonverbal Stroop tasks (Session 3). As discussed above, state manipulations of affect have been shown to influence performance on cognitive control tasks (e.g. Gray, 2001; Rowe et al., 2007; Shackman et al., 2006). Thus, it is possible that differences in the subjects' emotional states between sessions may have affected their performance on the various tasks that they performed, thus potentially obscuring the relationships between tasks in different sessions. In order to address this hypothesis, subjects should be tested on all four tasks (lexical, syntactic, verbal Stroop, and nonverbal Stroop) within the same experimental session in a future study.

Furthermore, it is important to note that the nonverbal Stroop task served as our only measure of conflict in the nonverbal domain compared with three tasks assessing conflict in the verbal domain. Thus, an interesting extension of the current study would involve the use of latent variables derived from several measures of both verbal and nonverbal conflict in order to obtain a "purer" measure of each (e.g. Friedman et al., 2008; Miyake et al., 2000). A latent-variable approach may allow us to more effectively examine the domain-generality of cognitive control mechanisms across verbal and nonverbal domains.

Individual Differences at the Genetic Level: Variation in Dopamine Regulation

We also investigated individual differences at the level of genetic variation. This approach enabled us to go beyond the question of *whether* processing mechanisms are related and instead, ask *how* they might be related. Genetic variation in the *COMT* gene, which plays an important role in dopamine regulation in prefrontal cortex, has been associated with variability in performance on cognitive control tasks (see Goldberg & Weinberger, 2004 for a review). As the verbal and nonverbal Stroop tasks as well as the lexical and syntactic ambiguity resolution tasks have been suggested to rely on cognitive control processing mechanisms, we tested the hypothesis that the *COMT* val158met polymorphism would be associated with performance on these tasks[9]. A marginally significant task x genotype interaction effect was found ($F[6,192] = 1.96$, $p = 0.07$), indicating a differential effect of *COMT* genotype across the four tasks. In order to investigate this interaction effect further, separate one-way ANOVAs were performed on the standardized residuals from each task. Only the ANOVA for the syntactic ambiguity resolution task yielded a significant main effect of genotype (results reported in Chapter 3). As discussed in Chapter 3, further investigation of this effect indicated that subjects with the val/val genotype showed a trend toward higher syntactic conflict scores compared to the other genotypes. Furthermore an exploratory analysis of subjects'

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[9] Data from 2 additional subjects were excluded from all genetic analyses due to missing data for one or more tasks. This left a total of 67 subjects for the genetic analyses across all four tasks. Standardized residuals were first calculated for each task, predicting subjects' performance on ambiguous trials from their performance on unambiguous trials. For the lexical ambiguity resolution task, subjects' reaction times on inconsistent trials were predicted from their reaction times on consistent trials. These standardized residuals were then submitted to a repeated-measures mixed ANOVA with the within-subjects factor of task (verbal Stroop, nonverbal Stroop, lexical, and syntactic) and the between-subjects factor of *COMT* val158met genotype.

reaction times for the lexical ambiguity resolution task revealed that subjects with the val/val genotype demonstrated significantly greater difficulty on trials containing a lexical ambiguity (consistent and inconsistent trials). Importantly, val/val subjects did not demonstrate greater difficulty for control and filler trials, demonstrating the specificity of the effect to processing lexical ambiguities.

How does this finding inform our understanding of the nature of the processing mechanisms underlying lexical and syntactic ambiguity resolution? Some researchers have found that subjects with the val/val genotype tend to demonstrate impaired performance on tasks that tap inhibitory control abilities, such as the stop-signal (e.g. Congdon, Constable, Lesch, & Canli, 2009) and flanker (e.g. Blasi et al., 2005) tasks. Both the syntactic and lexical ambiguity resolution tasks invoke conflict between competing linguistic representations. Successful performance on the lexical ambiguity resolution task may involve inhibition of the meaning of the lexically ambiguous word that is primed by the first word pair in order to judge the words in the target pair as related. Similarly, successful performance on the syntactic ambiguity resolution task may involve inhibition of the initial interpretation of the incorrect goal (e.g. the empty napkin) as a destination in order to successfully arrive at the correct interpretation of the linguistic input. Thus, if val/val individuals are characterized by impaired or inefficient inhibitory control mechanisms, they may experience increased difficulty in situations that require successful inhibition. Our finding that val/val individuals demonstrate greater difficulty in processing linguistic ambiguities parallels *COMT* findings in the cognitive control literature, where several studies have reported that subjects with the val/val genotype demonstrate greater difficulty on cognitive control tasks, such as the Wisconsin Card Sorting Task (e.g. Malhotra et al., 2002) and the n-back task (e.g. Goldberg et al., 2003). Although preliminary in nature and not statistically robust, our results constitute novel findings, as the resolution of lexical and syntactic ambiguities has not yet been investigated at the neurotransmitter level. In sum, beyond confirmation of the predictions of constraint-satisfaction theories, we were also able to shed light on the nature of the common processing mechanism that appears to resolve both lexical and syntactic ambiguities.

It is interesting to note that a significant association between *COMT* genotype and conflict resolution ability emerged for the linguistic ambiguity resolution tasks, but not for the Stroop tasks. This finding is surprising, given that the behavioral genetic literature on *COMT* has focused primarily on cognitive control tasks. However, the association between variation in *COMT* genotype and performance on the Stroop task has only been investigated in a few studies, and the results appear mixed (e.g. Reueter et al., 2005; Sommer, Fossella, Fan, & Posner, 2003). One possibility for our finding of an association between the *COMT* gene and performance on the lexical and syntactic tasks may stem from their greater sensitivity to processing difficulty. Subjects appear to have found the lexical ambiguity resolution task more difficult, in the form of higher error rates compared with the Stroop tasks. Furthermore, our measure of eye movements in the syntactic task may serve as a more sensitive measure of processing difficulty compared to reaction times in the Stroop tasks. Thus, it may be the case that there is an association between *COMT* and Stroop performance, albeit weak in nature, and we possessed insufficient power to detect this association. Consequently, enlarging our sample size may prove beneficial in detecting this association. Indeed, the sample size employed in the current study is smaller than is typically used in genetic association studies.

We also failed to find an association between individual differences in approach sensitivity and genetic variation in *COMT*. At first blush, this failure may seem surprising given the suggestion (discussed above) that both approach sensitivity and verbal cognitive control abilities rely on dopamine signaling pathways. However, it is important to note that although *COMT* plays an important role in the regulation of dopamine levels in the prefrontal cortex, several other genes, including DRD4, DRD2, and DAT, play key roles in dopamine regulation as well (see Goldberg & Weinberger, 2004 for a review). Furthermore, interactions between these genes have been associated with both personality traits (e.g. BAS sensitivity, Reuter, Schmitz, Corr, & Hennig, 2006) and cognitive control abilities (e.g. Kramer et al., 2007). As complex behaviors are likely to be supported by multiple genes, future investigations of individual differences in personality and ambiguity resolution abilities should include the study of gene-gene interactions.

CONCLUSIONS

The study of individual differences is essential to gaining a greater understanding of the psychological and neural systems that support behavior. The results of the current set of studies demonstrate how an individual-differences approach can be used to shed light on the processing mechanisms underlying several different domains of behavior. By looking at the areas of personality, cognitive control, and language processing through the lens of individual differences, we have uncovered meaningful sources of variability in human behavior. In particular, we have demonstrated that individual differences in personality dimensions are associated with variation in cognitive control abilities, suggestive of a hemisphere-specific organization of systems mediating motivational and cognitive control processing mechanisms. Additionally, we have shown that an individual-differences approach reveals commonality in processing across both behavioral and genetic levels for tasks featuring lexical and syntactic ambiguities.

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