Self Control in Society, Mind, and Brain

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CHAPTER 6

Using the Stroop Task to Study Emotion Regulation

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ABSTRACT

The Stroop task is among the most influential experimental paradigms for the study of cognitive control. Recent variants have sought to extend the Stroop task to the study of emotional regulation. To assess these emotional Stroop tasks, it is important to distinguish between those that seek to disrupt performance purely via distraction by emotional stimuli that engage attention, from those that do so by presenting emotional information that specifically conflicts with task-relevant judgments. The emotional stimuli in distraction-based Stroop tasks typically fail to disrupt the performance of healthy adults, and recent work suggests that when inference does occur, it lags behind goal-directed processing, primarily degrading performance on subsequent trials. Although early neuro-imaging research using the emotional distraction Stroop tasks gave rise to the influential hypothesis of distinct emotional and nonemotional processing regions in the anterior cingulate cortex, subsequent research has provided limited support. Other recent evidence suggests that interference in these distraction tasks might reflect a generic transient surprise rather than inherently emotional processes. In contrast to emotional distraction Stroop tasks, studies of emotional conflict have reported robust congruency effects, but it is unclear that the resolution of stimulus incompatibility is relevant to questions of how one controls one's emotions. Future research with emotional distraction Stroop tasks should seek to develop variants that evince more robust effects, whereas research on emotional stimulus incompatibility should leverage previous work with nonemotional conflict Stroop variants to explore topics such as the relationship between output modality and dimensional relevancy, and the distinction between categorization and identification task goals.

Keywords: Cognitive control, interference, emotional control, Stroop task, emotional Stroop, anterior cingulate cortex, conflict, distraction

Self-control broadly describes the goal-directed regulation of thought, feeling, and behavior. Although the history of experimental psychology offers countless paradigms developed to study self-control, perhaps none has achieved the renown or influence of the simple task Stroop described in 1935 (Stroop, 1935). Straightforward instructions guide the participant: identify the font color of a string of letters as quickly as possible, ignoring any meaning the letters may carry. This is easily done when the letters do not comprise words, or when they

comprise words that lack a strong color asso-
ciation. But what happens if the to-be-ignored
word names a color? The effect depends on the
relationship between the irrelevant word and
the relevant font color. If the word and font
color are compatible, such as the word "blue"
printed in blue, then participants often answer
faster, suggesting facilitation. Conversely, when
meaning and color are incompatible, such as the
word "red" printed in blue, participants typi-
cally respond slower, indicating interference.

This phenomenon has inspired a great deal
of work in the cognitive and neural sciences—
the Web of Science database records nearly
4,000 citations of Stroop's original paper (www.
isiwebofknowledge.com). To what can we attri-
bute such enduring impact? Perhaps most obvi-
ous is the unusual reliability and magnitude of
the interference effect (MacLeod, 1991). Stroop
interference is evident to anyone who attempts
the task. Furthermore, this interference is
remarkably difficult to circumvent—only a
handful of manipulations have been found to
substantially reduce or eliminate the disruption
(Alexander et al., 1989; Besner, 2001; Besner &
Stolz, 1999; Raz et al., 2003, 2006, 2007; Raz,
Shapiro, Fan, & Posner, 2002; Wenk-Sormaz,
2005).

Another major reason for the continued
popularity of the Stroop task is likely its ver-
satility. Interference has been demonstrated in
Stroop variants using a wide range of stimuli
(MacLeod, 1991; MacLeod & MacDonald,
2000), including pictures with embedded
words, such as the word "cat" printed inside a
drawing of a pig (Rosinski, Golinkoff, & Kukish,
1975); location words presented through head-
phones to a single ear, such as the word "left"
played through the right ear channel (Pieters,
1981); and digit sets of varying size, such as the
number "3" printed four times (Windes, 1968).
Among these many variants exists a growing
number in which emotional stimuli serve as the
source of the interference. Although these emo-
tional Stroop tasks are well-known in the emo-
tional control literature, we are aware of only
one published review that exclusively addresses
this work (Williams, Mathews, & MacLeod,
1996). In the 12 years since this review, both

the number and diversity of emotional Stroop
variants have increased dramatically. Moreover,
several recent experiments challenge the domi-
nant theoretical accounts of interference and
control offered earlier.

Given these developments, it seems appro-
priate to consider anew this body of work. We
begin below by summarizing several current
issues in the broader Stroop literature. Next,
we differentiate emotional Stroop variants that
seek to disrupt performance through dimen-
sional conflict, from those that do so through
distraction. Building on our earlier discussion,
we evaluate the fit between prominent models of
the traditional Stroop task and current findings
from these emotional Stroop variants. This first
section concludes with an examination of recent
evidence that interference and control processes
in both conflict and distraction tasks may per-
severe beyond the trial on which an emotional
stimulus is presented, influencing performance
and neural activity on subsequent trials.

We then turn our attention to a modern
iteration of the classic question that asks, "How
similar are emotional and nonemotional self-
control?" Since the advent of neuro-imaging,
researchers have increasingly looked to the
brain for answers, asking, "How similar are the
neural mechanisms that assert control in emo-
tional and nonemotional contexts?" The second
section first describes an early emotional Stroop
brain imaging study (Whalen et al., 1998) and
the influential hypothesis of distinct emotional
and nonemotional processing regions in the
anterior cingulate cortex (ACC) that it inspired
(Bush, Luu, & Posner, 2000). Next, we assess the
body of evidence that has amassed from both
conflict and distraction emotional Stroop neu-
ro-imaging studies in the years since the origi-
nal proposal. We conclude that the emotional
distinction hypothesis of the ACC requires sig-
nificant modification.

The third section considers several features
of emotional Stroop tasks that may limit the
contribution they ultimately make to emotional
control research. We begin by noting the funda-
mental constraints imposed by the quasi-exper-
imental design of emotional distraction Stroop
tasks, highlighting the problem of unequal

lexical characteristics between word lists. Next, we consider evidence that suggests that interference in these distraction tasks might reflect a transient surprise caused by salience in general, rather than interference that is specific to the processing of emotional stimuli. The third section turns our attention to emotional conflict variants, examining the pertinence of the interference between representations these tasks model, to the question of how one controls one's emotions. Finally, the chapter concludes with suggestions to guide future research.

ADAPTING THE STROOP PARADIGM TO THE STUDY OF EMOTIONAL REGULATION

The Classic Stroop Task: An Experimental Model of Self-Control

A complete theoretical account of the Stroop task must address two core phenomena. First, it must explain why identifying font color takes longer on incongruent trials. Second, it must explain why congruency does not similarly influence speed when the task is reversed (i.e., the participant must identify the word and ignore font color). The models that have been put forth to explain these phenomena generally adopt a framework of hierarchical processing stages. Common in cognitive psychology, such models assume that across these stages, increasingly abstract stimulus representations mediate the transformation of incoming sensory information into a goal-directed motor response. Whereas lower processing stages perform perceptual analyses and object recognition, higher stages glean semantic and contextual meaning. Representations at these higher stages then interact with representations encoding task rules and goals that guide selection of the correct response. Finally, the response must be mapped to a motoric sequence dictated by the task, and this sequence must be programmed and executed.

Considering Stroop interference within such a framework demands specificity about how the processes interact to degrade performance, and when and where they do so. Most current approaches assume that representations

of font color and word form are reflexively and simultaneously processed across early sensory and perceptual stages, but what happens to these two streams at higher levels is a matter of debate. One well-known view invokes the traditional distinction between automatic and controlled processes. An idea with over a century of history in psychological science (Cattell, 1886), automaticity describes highly practiced or hardwired processes that begin without intent, proceed by their own momentum, and persist in spite of volitional attempts to curtail them. In contrast, controlled processes must be initiated and sustained through the mobilization of attentional resources (Hasher & Zacks, 1979; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). Automaticity-based accounts of Stroop interference consider word reading to be an automatic process in literate adults, and thus assume word analysis proceeds reflexively through the higher processing stages. Color identification is not considered to be an automatic process, but if the goal is to identify font color, then analysis of font color must also continue. Controlled attention is invoked to guide processing through these higher stages, yielding an abstract representation for font color that can compete with the automatically evoked word representation to determine the participant's response. As described further below, the presence of coactive representation at response levels is believed to thwart selection processes, ultimately delaying response execution.

For many years, the chief strength of automaticity accounts was the elegant explanation they provided for the performance asymmetry between the standard and reverse goal versions of the classic color-word task (MacLeod, 1991; MacLeod & MacDonald, 2000). From this perspective, setting the goal to word identification would not affect the reflexive processing of words, but higher-stage analysis of font color identification would lack the support of controlled attention and thus come to a halt. Regardless of congruency, only representations activated by the word meaning pathway would thus be made available for response selection, resulting in equivalent performance. More recently, translational models have challenged

the conclusion that font color identification is inherently less automatic than word identification (Virzi & Egeth, 1985). This approach argues that asymmetrical interference emerges because word information is already represented in the required response modality, whereas color information must be translated into a verbal representation.[1] By analogy, it is not that word reading is automatic, but that the target this processing stream must reach is closer. But what if the task specifies a different target? According to the translational model, if changing the target differentially alters the translational demand required of representations from the two dimensions, then the symmetry of interference will also change. To test this, Durgin (2000, 2003) developed a Stroop variant in which the participant responds by pointing to color patches on the screen. Given that color identification no longer requires translation to the verbal domain, yet word identification now requires translation into the color domain, the translational model predicts the traditional asymmetry should be reversed (i.e., color identification performance should be unaffected by word meaning, but incongruent font color should disrupt word identification). Durgin found exactly that—a result apparently incompatible with automaticity accounts.

Although automaticity and translational accounts seek to explain the processes that lead to incompatible representations at higher stages of analysis, they do not explain why incompatible representations delay responding. Most accounts assume that response selection occurs when the activity level of a graded representation corresponding to that response is pushed above a preset threshold. For example, Logan's (1980) information accrual model envisions a response selection stage that sums output from parallel pathways processing each stimulus dimension. This output constitutes positive or negative support for each of the possible response options, so when the stimulus dimensions are congruent, both pathways contribute information in support of a particular response, allowing the preset threshold to be reached sooner. However, in the incongruent condition, information from the irrelevant dimension counts against

the correct response, increasing the amount of information needed from the relevant dimension for the response threshold to be reached. The increase in reaction time reflects the additional time needed to accrue this information.

A similar accrual mechanism determines responding in the neural network models developed by Cohen and colleagues. In these models, the strength of a representation is governed not just by the strength of previous representations in that pathway, but also by within-level inhibitory and facilitatory connections with competing representations (Cohen, Dunbar, & McClelland, 1990). More recent versions of the model have incorporated mechanisms for the monitoring and control of interference (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004). Information processing conflicts are first detected by a dedicated monitoring system, localized to the rostrodorsal ACC (rdACC), caudodorsal ACC (cdACC), and adjacent medial prefrontal cortex (MPFC). Often this monitoring system is described as multimodal, responding to conflicts across multiple levels of processing, although some have argued the ACC only monitors conflicts in response levels (Liu, Banich, Jacobson, & Tanabe, 2006; van Veen, Cohen, Botvinick, Stenger, & Carter, 2001). Regardless, when the monitoring system detects conflict, it cues the engagement of the task rule and goal representations in the lateral PFC that inhibit or facilitate processing at different processing stages, tipping the balance of activity in favor of the relevant processing stream (Botvinick et al., 2001, 2004; Kerns et al., 2004; Miller & Cohen, 2001). Crucially, the model does not allow these adjustments in control to take place quickly enough to impact the current trial. Thus, evidence for greater control in neural activity and performance can only be observed on the subsequent trial (Botvinick et al., 2001).

Conflict in Emotional Stroop Tasks

One approach to adapting the Stroop paradigm to questions of emotional control, has been to present stimuli with emotional dimensions that vary in congruency. Several studies have

combined emotional words and photographs of facial expressions (Anes & Kruer, 2004; Egner et al., 2007; Etkin et al., 2006; Haas et al., 2006; Preston & Stansfield, 2008; Stenberg, Wiking, & Dahl, 1998) or scenes (Park et al., 2008). For example, Hirsch and colleagues printed the words "happy" and "fear" across happy and fearful facial expressions (Egner et al., 2007; Etkin et al., 2006). As in an earlier behavioral experiment (Anes & Kruer, 2004), participants were required to identify the expression, but incongruent words disrupted performance. Other picture-word studies have required participants to categorize a word by valence or emotion, while ignoring the valence or emotional category of the accompanying image (Haas et al., 2006; Park et al., 2008; Preston & Stansfield, 2008, experiment 2; Stenberg et al., 1998). For example, in one experiment participants categorized words such as "party" and "pride" as positive or negative, while ignoring happy and sad facial expressions (Haas et al., 2006). These studies have also consistently reported degraded incongruent performance.

Considering these findings in the context of the broader Stroop literature raises several questions. Taking into account that both words and images can interfere when serving as the goal-irrelevant dimension, might suggest the absence of a goal-dependent performance asymmetry akin to that of the classic color-word task. Unfortunately, to our knowledge no study has directly tested this possibility by alternating dimensional relevancy using a single set of stimuli and consistent experimental parameters. Given that reading and emotional face processing are widely believed to occur with a high degree of automaticity, an automaticity-based account might predict behavioral interference regardless of dimensional relevancy. A translational model might predict a different outcome. In the tasks of Hirsch and colleagues (Egner et al., 2007; Etkin et al., 2006), to indicate the emotion conveyed by the facial expression, a nonverbal representation of the expression would need to be translated to the corresponding verbal representation; in contrast, the word representation is inherently verbal, and thus requires no additional translation once it has

been recognized. Thus, a translational model would likely predict little or no interference in a reversed-goal variant of the Hirsch task, in line with the lack of interference when the goal is reversed in the classic Stroop task.

Does the interference effect reported in word-relevant emotional Stroop variants then falsify the translational account? To provide an answer, we again turn to the broader Stroop literature. Stroop variants using nonemotional picture-word combinations first began to appear in the early 1970s (MacLeod, 1991). Typically the stimuli in these tasks featured words printed inside black and white line drawings. At first, the pattern of interference observed seemed to correspond to the color-word Stroop: when participants identified pictures, incongruent words disrupted performance, whereas word identification was unaffected by the congruency of the concurrent picture (Rosinski, Golinkoff, & Kukish, 1975). However, matters were complicated by the discovery that this performance asymmetry was reversed if participants were instructed to categorize the stimuli by object type—for example, responding "animal" when presented a picture of dog (Glaser & Dungelhoff, 1984; Smith & Magee, 1980). To account for these findings, Glaser and Glaser developed a model in which distinct processing units maintain semantic memory and the lexicon (Glaser & Glaser, 1989). They posited that word information has privileged access to the lexicon, whereas picture information has privileged access to semantic memory. Furthermore, they assumed that identification tasks rely on selection among lexical representations, but the critical selection for categorization tasks occurs at a semantic processing stage.

Combining this set of assumptions with a translation model of interference allows the Glaser and Glaser model to predict the observed outcomes of both emotional and nonemotional picture-word tasks. Incongruence disrupts performance when the irrelevant dimension has privileged access to the critical processing stage. Such is the case when the participant must identify the picture, as in emotional expression identification tasks (Anes & Kruer, 2004; Egner et al., 2007; Etkin et al., 2006), or categorize

a word, as in word emotion and valence categorization tasks (Haas et al., 2006; Park et al., 2008; Preston & Stansfield, 2008, experiment 2; Stenberg et al., 1998). In contrast, incongruence has little or no effect on performance when the relevant dimension has privileged access to the critical processing stage. Such is the case in tasks that require determination of the semantic category of pictures or the identification of words. Although nonemotional studies provide ample confirmation of this prediction, we know of only one test in the context of an emotional Stroop task. In a preliminary experiment, Preston and Stansfield (2008, experiment 1) required participants to identify the words "sad," "angry," "happy," and "scared," while ignoring corresponding facial expressions. They found a small but significant 25-millisecond difference between the congruent and incongruent conditions. Although this is smaller than the 68-millisecond difference they saw in the second experiment, which required categorization of words, the design was changed in numerous other ways, so a direct comparison of effect size cannot be made. Nonetheless, that this effect is considerably smaller than both typical Stroop effects and other face-word effects is consistent with the Glaser and Glaser model.

Other emotional Stroop variants have manipulated the congruency of prosodic and lexico-semantic dimensions in speech stimuli. Most often stimuli consist of a set of valenced words, each of which carries a positive vocal tone in one recording and a negative tone in another (Grimshaw, 1998; Ishii, Reyes, & Kitayama, 2003; Kitayama & Ishii, 2002; Schirmer & Kotz, 2003; Schirmer, Zysset, Kotz, & Yves von Cramon, 2004). For example, one study recorded words such as "pretty" and "bitter" spoken with both "smooth and round" and "harsh and constricted" tones (Ishii, Reyes, & Kitayama, 2003). Less often, full sentences have been used (Mitchell, 2006a, 2006b; Rota et al., 2007; Vingerhoets, Berckmoes, & Stroobant, 2003). For example, one study recorded sentences such as, "The dog had to be put down" and "She won the lottery jackpot" spoken with happy and sad prosody (Mitchell, 2006a). All but one of these emotional speech Stroop studies required participants to

categorize the relevant stimulus dimension. The singular exception might best be considered a hybrid identification-categorization task: participants either identified the words "mad," "sad," and "glad," or categorized the prosody these words carried (Grimshaw, 1998).

In contrast to the image-word variants discussed above, many of these studies examined interference in both dimensional relevance conditions (Grimshaw, 1998; Ishii et al., 2003; Kitayama & Ishii, 2002; Mitchell, 2006a; Schirmer & Kotz, 2003; Vingerhoets et al., 2003). Of the categorization studies reporting both conditions, all but one (Schirmer & Kotz, 2003) found bidirectional effects. These findings collectively suggest greater parity of access to the semantic processing stage between the prosodic and lexico–semantic stimulus dimensions than exists between the color and word dimensions of the classic Stroop task. A series of experiments by Ishii and colleagues suggest that even though prosodic–linguistic conflict might be bidirectional, interference effects show a culturally determined asymmetry (Ishii et al., 2003; Kitayama & Ishii, 2002). For example, American-born speakers of English demonstrated greater interference when identifying prosody valence, but native Japanese speakers and Tagalog-English bilinguals demonstrated greater interference when identifying word valence. These authors attributed the variability of the asymmetry in the populations to a broader difference in the emphasis eastern and western cultures place on contextual information, but the precise cognitive mechanisms that differentiate the processing streams remain unclear.

What results might the Glaser and Glaser (1989) model predict for the identification-categorization hybrid task described by Grimshaw (1998)? Given the parity of semantic access found in other studies, the model would likely anticipate interference during prosodic categorization. However, the privileged lexical access of printed words would presumably extend to spoken words, implying less or no interference in the identification portion of this experiment. In support of these predictions, robust conflict was found in the prosodic categorization

condition in two experiments, whereas in the word identification condition, performance was disturbed only slightly (experiment 2), or not at all (experiment 1).

Distraction in Emotional Stroop Tasks

Although conflict Stroop tasks model the disruption of selection mechanisms at critical points in the processing hierarchy, distraction variants model nonspecific performance declines caused by processing a salient, but irrelevant, stimulus dimension. Emotional distraction Stroop tasks typically mimic the format of the traditional color-word Stroop task, requiring the participant to identify the font color of words while ignoring word meaning (Williams et al., 1996). However, in place of the semantically incongruent color words of the traditional task, these distraction-based variants substitute emotional words. Interference is assessed by comparing latency or accuracy on emotional word trials with performance on neutral word trials. Although such a contrast roughly parallels the comparison between incongruent and neutral trials in conflict Stroop tasks, distraction tasks lack putative facilitation trials, making it impossible to find a similar parallel of the more common comparison with congruent trials.

The impossibility of a congruency effect points to a pair of broader characteristics that distinguishes the distraction of these tasks from the conflict of the traditional Stroop and the emotional variants discussed above. First, the relationship between stimulus dimensions is arbitrary: the value of the goal-relevant dimension on a given trial has no bearing on the classification of that trial in the experimental design. For example, if "cancer" is chosen to serve as a valenced word, then a trial in which "cancer" is printed in red constitutes an interference trial, just as a trial in which it is printed in blue, green, or any other color used in the response set. As we will discuss in the following section, this characteristic profoundly influences the interpretation of results in these tasks.

Arbitrariness also characterizes the relationship between the irrelevant dimension and the goal the participant is instructed to achieve. In emotional distraction Stroop tasks, the task goal need only yield a performance measure that allows the experimenter to compare disruption in the emotional and nonemotional conditions. In contrast, assigning the goal of color identification is essential for the incompatible words of the traditional Stroop to disturb performance. This flexibility of task goal in emotional distraction tasks has been usefully exploited in one popular variant, the emotional counting Stroop (Whalen et al., 1998). Although the counting task differs from standard emotional distraction Stroop tasks, in that the participant is required to indicate the number of instances of a word on the screen, the same affective and nonaffective words may be used as in the original color identification version. In contrast, counting analogs of the traditional Stroop must use number words, not color words, in the irrelevant dimension (Bush et al., 1998). The arbitrariness of the assigned goal in emotional distraction Stroop tasks has been further explored with direct empirical investigation. Several studies have found that emotional word lists associated with reduced color identification performance were similarly associated with reduced performance when featured in a speeded reading or lexical decision task[2] (Algom, Chajut, & Lev, 2004; Larsen, Mercer, & Balota, 2006).

The dissimilarity of conflict and distraction has led several authors to question whether a distraction-related performance deficit should be described as a Stroop effect. For example, McKenna and Sharma suggested "emotional intrusion effect" would be more appropriate (McKenna & Sharma, 2004), whereas Algom and colleagues offered the alternative "generic slowdown" (Algom et al., 2004). Although we chose to consider both emotional Stroop variants in the present review, our point is not to suggest they engender a similar type of interference or call upon similar cognitive mechanisms. To the contrary, the empirical data we review below consistently follows the theoretical distinction we have drawn thus far.

Perhaps at no point is this difference as clear as when we compare the performance decrement observed in the two variants. Emotional

conflict Stroop tasks consistently show robust effects, in line with the robust interference of the traditional Stroop task, but emotional distraction Stroop tasks typically report much smaller differences in performance, if performance between conditions differs at all. A recent meta-analysis of reaction time data from published accounts of color-word emotional distraction Stroop tasks, found that healthy, nonanxious adults responded with similar speed to both emotional and neutral words (Phaf & Kan, 2007). We do not take this to mean that distraction cannot be successfully modeled by these emotional Stroop variants. Several authors have observed small but consistent performance differences in carefully designed experiments (Algom et al., 2004; McKenna & Sharma, 2004). The meta-analytic null finding likely reflects a number of factors, including limited power at the level of the individual studies, and the inclusion of studies in which design factors inadvertently obscured an effect. However, the null finding also highlights the tenuous nature of distraction-based interference, further distinguishing distraction- and conflict-based Stroop tasks. As such, it is critical when considering emotional distraction Stroop tasks, to remain vigilant to the possibility that the emotional stimuli did not interfere with goal-directed processing, and to temper interpretation when no evidence of interference is provided by the performance data.

Subsequent Trial Interference in Emotional Distraction Stroop Tasks

Thus far, we have considered emotional interference and control only within the time frame of a single trial. Recent evidence from a number of sources suggests that a complete account will require that we expand our view, allowing for the possibility that these processes may exert influence not just within, but across trials also. An early indication of such extra-trial influence in emotional Stroop tasks came from the observation that blocked designs, in which trials are presented grouped by condition, showed a greater behavioral effect of emotional distraction than designs in which emotional and neutral trials were mixed (Algom et al., 2004; Cassiday, McNally, & Zeitlin, 1992; Jones-Chesters, Monsell, & Cooper, 1998; Kaspi, McNally, & Amir, 1995; Phaf & Kan, 2007; Richards et al., 1992; Waters & Feyerabend, 2000; Waters et al., 2005). Although the difference in performance between blocked and mixed designs could have resulted from nonspecific changes in motivation or some other aspect of mental set, these findings could also be accounted for by interference processes persisting beyond the trial on which the causal emotional stimulus appeared. If at least a portion of the interference effect from an emotional trial were spread across subsequent trials, then in mixed designs some of the subsequent latency might be attributed mistakenly to neutral trials, bringing the average reaction time down for the emotional condition and up for neutral condition.

Such temporally extended distraction could take one of at least three general forms. One possibility is that viewing the emotional stimuli induces a long-term change in emotional state in which performance is generally degraded compared to a neutral state. If a direct effect of the stimuli on the emotional state accounts for the greater performance disruption in blocked designs, we might expect this disruption to increase over time (Ehlers et al., 1988). A second possibility is that interference begins on a particular trial and persists into the next, but the disturbing influence wanes quickly. Evidence for this type of subsequent trial effect, which Waters and colleagues termed "carry-over effects" (Waters et al., 2005; Waters, Sayette, & Wertz, 2003), would be provided by data in which emotional stimuli independently accounted for decreased performance on both the presentation trial and subsequent trials. But what if one observed such a decrement subsequent to the presentation trial, but not on the presentation trial itself? Termed "slow effects" by McKenna and Sharma (2004), this might indicate that the presence of an emotional stimulus sets in motion a sequence of mental events that eventually lead to disruptive processes, but that goal-directed processing of the causal stimulus is completed before the disruptive portion of the sequence begins.[3] Finally, state,

carryover, and slow effects might manifest on emotional trials exclusively, indicating a cumulative or potentiating influence, or such effects might manifest universally, increasing latency on emotional and neutral trials alike.

At present, only a handful of emotional distraction Stroop studies provide results capable of distinguishing among the above possibilities. We know of no studies that support the state effects hypothesis by showing an increase in interference across blocked emotional stimuli. In contrast, several studies found evidence of habituation (MacKay et al., 2004; McKenna & Sharma, 1995), or no change in interference (Sharma, Albery, & Cook, 2001), a direct contradiction of the state effects hypothesis. We know of four reports that directly examined performance as a function of previous trial type. In each instance, subsequent trial effects were identified, though the type of subsequent effects varied (Kunde & Mauer, 2008; McKenna & Sharma, 2004; Waters et al., 2003, 2005). Carry-over effects were found with smokers (Waters et al., 2003, experiment 1) and heroin addicts (Waters et al., 2005, experiment 1) using drug-related words, whereas slow-effects were found with smokers using drug-related words (Waters et al., 2003, experiment 2), and healthy controls using negative words (McKenna & Sharma, 2004), situation-specific stress words (Waters et al., 2005, experiment 2), and positive and negative pictures (Kunde & Mauer, 2008). Several studies reported an interaction between previous and current trial type, indicative of a cumulative effect or potentiation (Kunde & Mauer, 2008; Waters et al., 2005).

Although evidence for the existence of some kind of sequential effect at this point seems strong, the current set of mixed results limits further specification. Although it may be the case that the different experimental designs demonstrate different types of sequential effects because of an unknown variable, another possibility is that the use of unbalanced stimulus orders has in some cases yielded artifactual results. McKenna and Sharma pointed out that if trial types do not follow one another with equal frequency in an experiment, a lopsided distribution of sequential effects can distort observed effects (McKenna & Sharma, 2004).[4] In a series of careful experiments that maintained the frequency of sequential trial types, the authors observed only slow effects. Given the precision of the design, and that the participants consisted of healthy individuals in a standard experimental context, we believe the existence of slow effects seems to be the best supported finding at this time.

McKenna and Sharma further demonstrated that the slow effects they observed occurred on just the single trial following a negative word. Given the timing of stimulus presentation in their design, this implies the interference occurred within the second following response execution for the previous trial. This result is consistent with other work, showing that block design studies using very short gaps between trials, such as 32 milliseconds or 40 milliseconds, yielded greater interference effects than longer gaps, such as 1000 milliseconds or 500 milliseconds (Sharma & McKenna, 2001; van Hooff et al., 2008). However, other studies have reported subsequent effects with gaps between trials of 1000 milliseconds (Kunde & Mauer, 2008; Waters et al., 2005), 1500 milliseconds (Waters et al., 2005), and 2200 milliseconds (Waters et al., 2003). The extended interference in these studies may result in part from unique factors such as the use of picture stimuli (Kunde & Mauer, 2008), drug-addicted participants (Waters et al., 2005, Waters, 2003 #128), stress induction, context-specific words, or intoxication (Waters et al., 2005). Future studies will need to isolate and test the various possibilities to determine the precise temporal duration of the phenomenon and any factors that might modulate this duration.

Subsequent Trial Control in Emotional Conflict Stroop Tasks

To our knowledge, only Hirsch and colleagues have reported analyses of subsequent trial effects in an emotional conflict Stroop task (Egner et al., 2007; Etkin et al., 2006). In two neuroimaging studies, participants classified facial expressions as happy or fearful while ignoring the words "happy" or "fear" printed over each

image. Following an approach developed in earlier work with nonemotional conflict tasks (Botvinick et al., 1999; Egner & Hirsch, 2005b; Gratton, Coles, & Donchin, 1992; Kerns et al., 2004), the authors compared performance on incongruent trials grouped according to the congruency of the previous trial. In line with findings in these earlier nonemotional studies, participants responded more quickly when the preceding trial was also incongruent (II trials) than when it was congruent (CI trials). Neural activity was also lower in the II trials in a portion of the midline rostrodorsal MPFC (Etkin et al., 2006) and in the right rdACC (Egner et al., 2007), again paralleling previous analyses with the classic color-word Stroop task (Kerns et al., 2004) and a nonemotional face-word variant (Egner & Hirsch, 2005a). The authors interpreted these findings in the conflict monitoring framework developed by Cohen and colleagues (Botvinick et al., 2001, 2004), positing that the detection of conflict on the preceding incongruent trial initiated a reactive increase in control. Increased control then reduced conflict on the subsequent trial, resulting in better performance and less detection-related activity in the ACC.

In contrast to the large literature examining the conflict monitoring hypothesis of Cohen and colleagues, the reactive control proposed by these models has been addressed only briefly. In previous work, Hirsch and colleagues reasoned that if greater activity in CI trials reflects conflict monitoring, then greater activity in II trials might correspond to the implementation of reactive control (Egner & Hirsch, 2005a, 2005b). In both emotional Stroop studies, this reverse contrast (II>CI) identified greater activity in left pgACC and adjacent MPFC. One possibility is that these clusters reflect representations of transient task rules or goals. In the models of Cohen and colleagues, reactive control is accomplished by strengthening PFC representations that code these rules and goals. As these representations are stronger, they alter connection weights across the processing hierarchy in favor of the goal-relevant dimension. In the emotional face-word task, rule or goal representations might serve to direct attention to the facial stimulus or otherwise

facilitate processing in this pathway. However, this region did not show differential activity in a gender-identification task in which the same face images were instead combined with the words "male" and "female" (Egner et al., 2007). This suggests that in the emotion identification task, greater pgACC activity might specifically reflect the engagement of representations guiding assessment of the emotional aspect of the expressions. Consistent with such an interpretation, other work has associated this pregenual area with the perception of emotional stimuli in a wide variety of tasks (Wager et al., 2008).

However, interpreting activity differences in this pregenual region can be challenging. Another recent imaging study found decreases from baseline activity in this area during a word-scene valence categorization Stroop task, with greater decreases on incongruent than congruent trials (Park et al., 2008). Other work has reported activity reductions in the pgACC in both emotional (Gusnard et al., 2001) and nonemotional tasks (Gusnard et al., 2001; Mason et al., 2007), a pattern seen in a distributed set of brain regions. Paralleling this set of task-negative regions, goal-directed processing across many different tasks appears to engage a separate set of regions, including the rdACC and MPFC areas that Hirsch and colleagues identified in the CI>II contrast. Consistent with the findings of Hirsch and colleagues, activity in these goal-directed regions has been found to correlate negatively with activity in the task-negative (Fox & Raichle, 2007; Fox et al., 2005). Other work has found a greater activity reduction in the pregenual area during novel compared to practiced task blocks (Mason et al., 2007), and during blocks of speeded, incongruent trials compared to blocks of slower and congruent trials in a variant of the traditional Stroop task (Matthews et al., 2004). These findings suggest that the greater pregenual activity observed in the II trials might reflect the reduced challenge that increased control confers, rather than representations or processes specific to the instantiation of control.

These subsequent trial analyses support at least two important conclusions. First, the pattern of reaction time data, and to some degree

the fMRI results as well, reinforce the similarity between emotional conflict Stroop tasks and other tasks that model conflict-based interference, including the classic color-word Stroop task. As we highlight throughout this chapter, this similarity confers a unique opportunity to utilize techniques developed in the long history of nonemotional conflict research, and the work of Hirsch and colleagues demonstrates this opportunity. Second, although no study yet has directly compared subsequent trial effects between conflict- and distraction-based emotional Stroop tasks, surveying the current literature suggests distinct phenomena. Although conflict may invoke control processes that result in improved performance on subsequent incongruent trials, emotional distraction seems to degrade subsequent performance, even on neutral trials. More broadly, this dissimilarity reinforces the contention that emotional distraction and conflict Stroop tasks involve dissimilar types of interference.

ARE EMOTIONAL CONTROL MECHANISMS IN MPFC DISTINCT FROM THOSE THAT IMPLEMENT NON-EMOTIONAL CONTROL?

A Neural Instantiation of a Traditional View

The cognitive sciences have long struggled to understand how the human brain balances two fundamental demands: *(1)* it must retain the flexibility to respond to an infinite diversity of possible situations and *(2)* it must do so efficiently as cranial space is limited and the metabolic needs of neural tissue are high. Although it is now clear that a substantial degree of localization characterizes neural mechanisms across domains ranging from perceptual to mnemonic and linguistic processing, the field continues to question the nature and degree of specificity among the control functions of the prefrontal cortex. For example, a good deal of work has debated whether the control functions of working memory are material-dependent (Smith & Jonides, 1999; Wager & Smith, 2003).

A similar question has asked whether emotional and nonemotional control rely on distinct neural mechanisms (Ochsner & Gross, 2005). One particularly influential answer to this question has claimed that such a distinction characterizes the ACC, with tissue extending posterior and superior from the rdACC dedicated to nonemotional processing, and tissue extending anterior and inferior from the rdACC dedicated to emotional processing (Bush et al., 2000). This emotional distinction hypothesis emerged from an early neuro-imaging experiment in which participants performed two separate counting Stroop tasks in a single scanning session. In a task modeling nonemotional conflict, the authors reported worse performance and greater cdACC activity in incongruent blocks, in line with expectations based on previous work (Bush et al., 1998). In contrast, a second task modeling emotional distraction revealed greater emotional compared to neutral word activity in the rdACC (Whalen et al., 1998).[5] The authors suggested this rdACC activity might reflect a regulatory or monitoring function for emotional material parallel to the putative role of the cdACC in nonemotional interference. In a well-known review that followed, a summary of results from a number of neuro-imaging studies was presented alongside the findings from these counting Stroop tasks to support the proposed emotional distinction hypothesis (Bush et al., 2000).

Although widely cited, the study by Whalen et al. poses several inferential challenges. First, as we have emphasized throughout, distraction-based interference differs theoretically and empirically from conflict-based interference. If we observe distinct regulatory activity in emotional distraction and nonemotional conflict, we cannot know if this divergence reflects differences in the type of interference or the emotional nature of the stimuli. Second, the nonemotional task was always the first of the two performed in the session. This lack of counterbalance further confounds emotional content with both time spent in the scanning environment and task exposure. Third, performance was equivalent in the emotional and neutral word blocks of the distraction task, but in the conflict Stroop task, performance varied with congruency. At best, this asymmetry might indicate that the

neuro-imaging results are confounded by gross differences in the level of interference induced by the two tasks. At worst, the neuro-imaging results in the distraction task may not represent interference at all. As we argue throughout this chapter, reduced behavioral performance provides essential evidence for any claim of interference. A fourth inferential challenge is posed by the transient nature of the rdACC activity observed in the distraction task. The task was performed in two sets of alternating blocks, separated by a short break. The authors reported that they only observed a difference between the emotional and neutral conditions when they removed from analysis the second half of each of the two data sets collected. As we discuss further below, this transience might indicate that the neuro-imaging activity reflects a more general salience processing rather than emotional processing in particular. Finally, the report lacked formal tests of the emotional distinction hypothesis. The authors appealed to visual inspection of contrast maps of the two tasks, but informal assessment cannot replace statistical analysis of neuro-imaging data anymore than it can do so when comparing other types of data.

Emotional Interference in the Rostrodorsal Anterior Cingulate Cortex

A lack of consistency across studies further challenges the emotional distinction hypothesis. Of the six other studies we have identified that report imaging data of healthy adults performing the emotional distraction Stroop tasks (Compton et al., 2003; George et al., 1994; Herrington et al., 2005; Isenberg et al., 1999; Mohanty et al., 2007), only one found similar rdACC activity (Mohanty et al., 2007). This single replication is noteworthy, as the authors designed the study with the intention to overcome several of the limitations in the work of Bush and colleagues: the order of nonemotional conflict and emotional distraction Stroop blocks were counterbalanced across participants; analyses included the blocks in their entirety; and formal statistical tests confirmed the proposed region-by-task interaction. Despite these improvements, the design did not overcome

other serious limitations of the earlier work of Bush and colleagues: most critically, the tasks compared distinct types of interference, distraction and conflict, and no performance decrement was observed in the emotional task.

A number of conflict-based neuro-imaging studies have also compared emotional and nonemotional Stroop tasks free from these serious limitations. As noted above, Hirsch and colleagues have found greater activity in left pgACC and MPFC contrasting II>CI trials in face-word conflict tasks (Egner et al., 2007; Etkin et al., 2006). The coordinates they report place these clusters some distance away from that found by Whalen et al. (Whalen et al., 1998), but within the expanse of tissue Bush and colleagues considered the emotional division of the ACC (Bush et al., 2000). Several other emotional conflict Stroop studies have also reported pregenual activity. Having asked participants to identify prosody as angry, sad, happy or neutral, Rota and colleagues compared incongruent sentences to sentences which were either congruent or contained at least one neutral dimension (Rota et al., 2007). The authors reported only two activation peaks, both very close to the midline in the pgACC and pregenual MPFC. However, the inclusion of both congruent and neutral element trials in this contrast muddies interpretation. In addition, the incongruent trials also contained a greater number of emotional elements, on average, and so the pregenual differences might simply reflect greater emotional input. As discussed above, a recent word-image conflict Stroop study also reported activity differences in the left pgACC and pregenual MPFC (Park et al., 2008), but in the opposite direction of Rota and colleagues; that is, greater activity was found in the congruent trials than in the incongruent trials.[6]

Emotional and Nonemotional Interference in the Dorsal Anterior Cingulate Cortex

Emotional conflict Stroop studies have also reported greater activity in the rdACC on incongruent compared to congruent blocks (Haas et al., 2006) and on CI>II trials (Egner et al., 2007). Although these conflict-related clusters appear to fall within an area of overlap among

the emotional and nonemotional tasks classified by Bush and colleagues (Bush et al., 2000), the authors of both papers concluded the locations implied a domain-general conflict monitoring mechanism, in argument against the emotional distinction hypothesis. To bolster this claim, Egner and colleagues performed a similar CI>II analysis on data from a gender identification task in which conflict arose from incongruent gender labels. They identified a cluster of activated voxels with a peak in the left cdACC, consistent with previous research supporting a role for this area in nonemotional conflict monitoring. Furthermore, a portion of this cluster overlapped with the area identified in the emotional task. This shared area showed a main effect of CI>II across tasks, indicating consistent participation for the region regardless of the emotional nature of the conflicting dimensions.

Results from other emotional Stroop studies further challenge the emotional distinction hypothesis. In an earlier study, Hirsch and colleagues reported CI>II activity in their face-word task in a portion of dorsal MPFC, far from the proposed affective division (Etkin et al., 2006), and two emotional distraction Stroop studies also found emotion-related increases in dorsal MPFC (Compton et al., 2003; Isenberg et al., 1999). More direct evidence of emotion-related processing in the cdACC was provided by a rare human cellular recording study of OCD patients immediately prior to therapeutic cingulotomy targeting this region (Davis et al., 2005). The authors identified cdACC neurons that responded to both emotional distraction and nonemotional conflict counting Stroop tasks. Furthermore, the proportion of cells showing greater or exclusive response in negative word compared to the neutral word blocks (10/24), was much higher than the proportion of cells showing greater or exclusive response in the incongruent compared to neutral word blocks (2/20). A similar effect was seen when comparing a block of OCD-related words to the neutral condition (7/25). Although the relationship of such neuronal activity to the hemodynamic signal observed in fMRI remains unclear, this study provides unique evidence that neurons in the cdACC play a role in processing negative

word stimuli in the context of a distraction Stroop task.

Taken as a whole, we believe the current set of emotional Stroop findings advocate revision of the emotional distinction hypothesis. The dorsal portion of the ACC that Bush and colleagues (2000) believed exclusive to nonemotional processing, has been repeatedly observed in both emotional and nonemotional Stroop neuro-imaging studies, in line with similar work comparing emotional and nonemotional interference (e.g., Fichtenholtz et al., 2004; Yamasaki, LaBar, & McCarthy, 2002). Although the precise computations supported by this tissue remain unclear, the overlapping activity suggests that they serve a common function regardless of the eliciting stimulus. The validity of the second half of the emotional distinction hypothesis, that the rostral and ventral portion of the ACC participate exclusively in emotional processing, also remains unclear. Although numerous emotional Stroop studies have identified interference-related activity in rdACC and pgACC, null findings are equally common. Furthermore, interpretation of the reported activations is difficult because they may reflect differential task-related activity reductions. Going forward, it will be important to determine if the relatively greater emotion-related activity that has been seen, reflects an active role in emotion-related processing, or if it is simply a passive byproduct of other processes. If this region does actively participate in emotional processing, further work should attempt to isolate the eliciting factors to account for the inconsistency of the current emotional Stroop literature. Finally, future work should consider the possibility that the rostrodorsal and pregenual regions serve distinct functions.

IS INTERFERENCE A RESULT OF EMOTIONAL RELEVANCE OR OTHER STIMULUS PROPERTIES?

Quasi-Experimental Design in Emotional Distraction Stroop Tasks

A critical feature of experimental design is the control of extraneous variables that may

obscure a true effect or confound an observed effect. Recently Larsen and colleagues argued the design of emotional distraction Stroop tasks is quasi-experimental because the words that comprise the valenced and neutral conditions cannot be assigned randomly (Larsen et al., 2006). Such nonrandom assignment incurs the risk that incidental differences between the lists might drive differences in performance. For example, given that word frequency has been shown to modulate the speed of font color identification (Burt, 1994, 1999, 2002; Monsell, Taylor, & Murphy, 2001), if the words in the emotional and nonemotional lists in a distraction Stroop task vary in frequency, then one might spuriously attribute a frequency-driven performance decrement to emotional distraction.

To test whether lexical differences between word lists might confound interpretation of emotional distraction Stroop tasks, Larsen and colleagues analyzed over 1000 unique word stimuli from 32 published reports (Larsen et al., 2006). Using a large collection of lexical decision and word identification data, the authors compared average performance on words culled from emotional and neutral Stroop lists. The emotional words were associated with slower and less accurate responding, consistent with previous findings that have linked performance in similar lexical and emotional distraction Stroop tasks (Algom et al., 2004). However, Larsen and colleagues also showed that these emotional words were longer, less frequently used, and had smaller orthographic neighborhoods[7] than the neutral words. Each of these factors is known to contribute to slower and less accurate word recognition and lexical assessment, independent of semantic content. When these factors were included in the statistical model, the performance difference between emotional and neutral words disappeared.

Quasi-experimental designs have played an important role in many research domains because they allow researchers to ask questions when experimental designs do not. Yet these results recommend caution when interpreting the existing emotional distraction Stroop literature. So that readers may exercise such caution judiciously, the authors provided tables with the lexical metrics that they calculated for each Stroop study in their analysis (Larsen et al., 2006). To help correct for such problems in future work, they further offered to provide word lists upon request that equate for the problematic lexical factors they identified. Although these efforts allow for needed improvements, the use of balanced lists does not change the underlying quasi-experimental nature of distraction Stroop tasks, and so leaves the manipulation open to the influence of unknown systematic bias. In contrast, the experimental design of conflict Stroop tasks avoids such ambiguity: using identical color words in both the incongruent and congruent conditions ensures equivalence.

Salience in Emotional Distraction Stroop Tasks

The construct validity of emotional distraction Stroop tasks is further challenged by other findings that suggest that the interference observed is not specific to emotional stimuli. Although the meta-analysis conducted by Phaf and Kan found no support for increased emotional word latency in healthy, non-anxious adults, an effect was found in several analyses with high-anxiety and clinical participants (Phaf & Kan, 2007). One possibility is that the poorer performance of these participants reflects pathological attentional control deficits. Alternatively, some have suggested that emotional words possess greater relevance to clinical and anxious participants, and that this greater relevance potentiates their emotional impact, increasing distraction and reducing performance. If so, the meta-analytic null finding in healthy adults might reflect insufficiently emotional stimuli, a problem that could be remedied by making the stimuli personally relevant. In support of this view, items individually tailored to affectively positive and negative concerns of healthy participants reduced performance compared to items that were not self-relevant (Giles & Cairns, 1989; Riemann & McNally, 1995), just as food words reduced performance in hungry, but not satiated, participants (Channon & Hayward, 1990).

However, the hypothesis that self-relevant emotional words interfere with performance because of heightened emotional impact, is challenged by findings in several nonemotional distraction Stroop Tasks. Interference has been found with marginally emotional but clearly self-relevant words, drawn from hobbies and interests (Dalgleish, 1995) and biographical information (Gronau, Ben-Shakhar, & Cohen, 2005; Gronau, Cohen, & Ben-Shakhar, 2003). In one attempt to resolve this ambiguity, participants performed a distraction Stroop task that included individually selected words culled from emotional and neutral memories, as well as standard emotional and neutral words (Gilboa-Schechtman et al., 2000). Reaction times were slower for standard emotional compared to neutral words, but only when congruent in valence to a film shown immediately before. Furthermore, reaction times were slower for individually selected compared to standard words regardless of whether they were emotional or neutral. Together, these results argue that relevance more profoundly determines distraction than emotional meaning.

Some evidence suggests this argument may need to be taken further. One set of distraction Stroop tasks has used salient words such as curses and out-group slurs (MacKay & Ahmetzanov, 2005; MacKay et al., 2004; Siegrist, 1995). Although some of these words may carry emotional or self-relevant meaning for certain participants, most seem unlikely to do so. Although fewer in number than emotional distraction Stroop studies, the existing literature indicates these salient words may more robustly disturb performance. The hypothesis that interference in distraction Stroop tasks primarily reflects salience or surprise is further supported by the transience of the effect. Rapid attenuation has been reported in both behavioral (MacKay et al., 2004; McKenna & Sharma, 1995) and brain (Whalen et al., 1998) difference measures.

Of course, describing distracting words as salient risks tautology. Predictive power rests on identifying the determinants of word salience. The distraction Stroop literature implicates a diverse set of factors, including situational and personal relevance, lexical qualities, and familiarity. Overall, the emotional content of a word seems to contribute only weakly to salience, if it independently contributes at all. Moving forward, a more fruitful approach might consider emotional distraction Stroop tasks as continuous with other distraction Stroop variants. Such an approach would call first for more comprehensive efforts to determine the relative contributions of the various factors that seem to slow color naming, followed by efforts to compare the mechanisms supporting performance as a function of both distraction degree and kind.

Is Emotional Stroop Conflict Truly Emotional?

Following closely the model of the classic Stroop task, emotional conflict variants avoid the ambiguities of quasi-experimental design. Yet the theoretical and empirical overlap between these tasks raises validity concerns of a different kind. As described above, variants of the Stroop have used a wide range of stimuli. The present chapter has followed previous work and used the term "emotional conflict" to describe interference between incompatible emotional dimensions. However, convention yields inconsistent terminology, as it prohibits the use of parallel terms such as "color conflict" or "number conflict" to describe interference between nonemotional stimuli. Uniquely terming emotional conflict according to stimulus type may betray an a priori bias of the emotional conflict Stroop literature to assume distinct emotional processes.

In our view, whether conflict should be considered distinct when arising from incompatible emotional dimensions, depends on where and how selection occurs. To warrant distinction, the critical point of selection must occur in a uniquely emotional processing stage or neural system, or the mechanisms supporting this selection must be unique. However, we do not believe that uniquely emotional conflict is a prerequisite for emotional conflict Stroop tasks to help advance our understanding of emotional processing. Just as word- and speech-based Stroop tasks have contributed extensively

to knowledge about linguistic processing, so too could emotional Stroop tasks help define the hierarchy of processing stages that evaluate emotional stimuli.

WHERE TO GO FROM HERE?

As we have emphasized throughout this review, emotional conflict and distraction Stroop tasks model theoretically distinct types of interference. In conflict, the selection of a correct representation is thwarted by concurrent activation of an incorrect representation. This form of interference is specific: representations conflict because of the relationship between the relevant stimulus dimension, the irrelevant dimension, and the task goal. In contrast, distraction is a general form of interference, driven by inherent qualities of the irrelevant stimulus dimension. The relevant dimension and the goal are arbitrary: goal-related processes serve only to measure the disruptive influence of the irrelevant dimension.

This distinction is evident in the divergent findings of emotional conflict and distraction Stroop tasks. Although studies of emotional conflict report robust congruency effects, emotional stimuli in the distraction Stroop tasks typically fail to disrupt the performance of healthy adults (Phaf & Kan, 2007). When disruption does occur in these distraction tasks, recent work suggests the processes mediating interference lag behind goal-directed processing, perhaps only degrading performance when the gap between trials is shorter than this lag (Kunde & Mauer, 2008; McKenna & Sharma, 2004; Waters et al., 2003, 2005). Between-trial effects have also been found in emotional conflict tasks (Egner et al., 2007; Etkin et al., 2006), but rather than extended interference, conflict seems to invoke greater attentional control, resulting in better performance on subsequent incongruent trials.

It is especially important to recognize these differences when seeking to compare emotional and nonemotional interference resolution. Comparing matched emotional and nonemotional conflict variants, as in the recent work of Hirsch and colleagues (Egner et al., 2007), asks whether emotional stimuli conflict at distinct processing stages, and whether overlapping mechanisms are called upon to resolve this conflict. Other studies have compared emotional distraction and nonemotional conflict variants. This approach confounds changes in interference and stimulus type: if we observe unique mechanisms in emotional and nonemotional Stroop tasks, we cannot know if this divergence reflects a difference between nonemotional and emotional interference, or a difference between specific and general interference. The obvious solution is to contrast distracting emotional conditions with equally distracting nonemotional conditions. A few behavioral studies have taken this approach (e.g., Gilboa-Schechtman et al., 2000), however, we do not know of any imaging studies that have yet done so.

Both emotional conflict and distraction Stroop tasks offer exciting opportunities for future research. The path forward for work with emotional conflict Stroop tasks is clearer: researchers should follow in the footsteps left by many years of productive work with nonemotional conflict variants. The utility of such an approach already has been demonstrated in the subsequent trial analyses of Hirsch and colleagues (Egner et al., 2007; Etkin et al., 2006), which built on earlier work in traditional conflict tasks (Botvinick et al., 1999; Gratton et al., 1992; Kerns et al., 2004), and in the examination of goal-related performance asymmetries by Ishii and colleagues, which used the well-known technique of dimensional relevancy reversal from the classic color-word task to demonstrate cultural influences on speech processing (Ishii et al., 2003; Kitayama & Ishii, 2002). Especially promising opportunities for future research might build on nonemotional Stroop paradigms that relate output modality and dimensional relevancy (Durgin, 2000, 2003), and categorization and identification task goals (Glaser & Dungelhoff, 1984; Glaser & Glaser, 1989).

Research with emotional distraction Stroop tasks faces a more challenging path forward. Given evidence that interference in these paradigms may be driven less by the emotional nature of the stimuli than by personal relevance, familiarity, and lexical factors, future

efforts should seek to determine more broadly the characteristics of stimuli, emotional or otherwise, which confer salience. Subsequent trial distraction effects offer another intriguing avenue for future work. However, the success of any effort to model emotional distraction rests on whether it provides clear evidence of inference through disrupted performance. Such evidence has been particularly lacking in neuro-imaging using emotional distraction tasks. Some have suggested that observed differences in neural activity might represent a liminal interference too subtle to impact cruder behavioral measures of performance, however, we caution against this approach. Such claims rely on a level of reverse inference that current neuro-imaging techniques do not provide, and perhaps never will. Moreover, the quasi-experimental nature of these tasks leaves a clear opening for alternative explanations. Yet, even if observed activity did reflect subtle distraction, we would question the value of studying interference of such minimal behavioral consequence. A greater contribution might be made by developing tasks that evince more robust effects.

Our primary goal in writing this chapter was to provide the first comprehensive review of emotional Stroop tasks. The valuable contributions these Stroop variants already have made to the study of emotional interference and control, testifies to the wisdom of adapting robust and versatile paradigms from nonemotional work. A second goal of this chapter was to leverage the detailed theoretical accounts of the broader Stroop literature in assessing current emotional Stroop research. In doing so, we have emphasized the distinction between conflict- and distraction-based interference, a prerequisite for meaningful review of this work. We have also drawn novel connections between recent emotional variants and the more extensive corpus of nonemotional Stroop research. These connections suggest important alternative explanations and offer compelling paradigms to test them. We hope that in highlighting just a handful of these possibilities we have revealed sufficient promise to inspire deeper integration between future emotional and nonemotional Stroop research.

NOTES

1   Note that the translational model assumes verbal representations mediate response selection, not just when a spoken answer is given: in line with other perspectives, if the task requires a motor act such as a button press be made to indicate the response, it is believed that the appropriate verbal representation is first selected, and then mapped to the motor response according to task-specific rules. Thus, whether button presses or speech are used to indicate the response, it does not change the prediction of the translational model.

2   First developed by the prominent cognitive psychologist David Meyer, lexical decision tasks compare performance when determining whether letter-strings constitute words (Meyer & Schvaneveldt, 1971).

3   Waters and colleagues do not appear to distinguish carry-over and slow effects. Thus, in experiment 2 of Waters et al. (2003), they describe a subsequent trial latency increase for smoking words as a carryover effect in the absence of a fast-effect. According to our nomenclature this effect would be a slow effect.

4   In a striking demonstration of this, the authors constrained trial order such that trials following a particular type were more likely to be of the opposite type, and the sequential effects of negative trials preferentially impacted neutral trials. Using words that had produced a 30ms emotional latency difference in an earlier blocked study (McKenna & Sharma, 1995), the constrained trial order now produced a reverse interference effect of 18 ms.

5   Similar to the pgACC activity elicited by the emotional scene-word conflict Stroop task we discussed earlier (Park et al., 2008), rdACC activity in this distraction counting Stroop task was lower in both the neutral and emotional conditions, than in the task baseline. Greater activity in the emotional blocks might therefore be more accurately described as less negative than that of the neutral condition.

6   As noted above, baseline activity was higher in both the congruent and incongruent conditions in this task.

7   The orthographic neighborhood of a target work is the number of other words that the target word can be transformed into by changing just one of its letters.

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