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Dissociation of perceptual and motor inhibition processes through the use of novel computerized conflict tasks

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Abstract

Efficient behavioral functioning requires early perceptual inhibition of irrelevant stimuli and later motor inhibition of inappropriate responses. The Perceptual and Motor Conflict Tasks were developed to differentially assess perceptual and motor inhibition, and to determine whether these processes utilize separate or shared cognitive resources. The computerized tasks include six subtests involving a box or an arrow appearing in various locations. Subjects respond by pressing a key on the left or right side of a keyboard. In different subtests, arrow direction or stimulus location determines correct responses. Perceptual inhibition assessment requires the subject to respond to a conflicting arrow direction while ignoring stimulus location. Motor inhibition assessment involves the subject responding in the direction opposite to that indicated by a centrally located arrow. In a neurologically normal sample ($N = 44$), reaction time analyses yielded significant Perceptual and Motor Conflict main effects, with slower performance under conflict conditions, but no significant Perceptual × Motor interaction. The lack of a significant Perceptual × Motor interaction, according to the additive factor model, indicates that these two processes utilize distinct cognitive resources. Nevertheless, performance on the two conflict tasks was significantly correlated with each other, and Perceptual Conflict performance was significantly correlated with Stroop interference. (*JINS*, 2003, *9*, 25–30.)

Keywords: Conflict, Inhibitory control, Motor inhibition, Perceptual inhibition

INTRODUCTION

Efficient information processing requires inhibition at an early perceptual stage to prevent the interfering effect of irrelevant stimuli and later motor inhibition to prevent execution of inappropriate responses. An array of methods has been developed to elucidate the nature of these cognitive processes and the neural mechanisms that mediate them. The Stroop (1935) effect is among the most frequently used methods to study these processes. The Stroop task involves the presentation of color-words printed in incongruent ink colors (e.g., the word “red” printed in green ink). The challenge is to name the ink color while ignoring the printed word. Thus, the individual must select the appropriate stimulus (i.e., the ink color), while inhibiting the more prepotent response to (name) the written word. The increase in response time during the incongruent condition is referred to as the Stroop interference effect.

The interference phenomenon observed in the Stroop task has been investigated extensively. Originally, it was assumed that the Stroop Color-Word interference effect was due to a simple difference in speed of processing of the ink color and the color-word. Several theories suggested that the observed interference resulted from processing of the different dimensions (color and word) having to pass through a single central response channel (Dyer, 1973; Glaser & Dolt, 1977; Morton, 1969; Palef & Olsen, 1975). For literate individuals, the more salient response is the written color-word. These “race-horse” models purported that there was a bottleneck of information at the motor output, resulting in the delayed reaction time. However, speed of processing models failed to explain why the actual response made was not the response to the distracter (color-word) if the distracter was actually being processed faster. Further, the

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speed-of-processing models provided no explanation of a mechanism for the actual response selection decision. These weaknesses in the models led researchers to look beyond a basic late motor response conflict.

More than a half of a century of research has shown that an acceptable explanation of Stroop interference must involve more than a difference in speed of processing. Among literate individuals, irrelevant stimuli (color-words) in the Stroop task are more salient than the relevant stimuli (ink color), which makes inhibition more difficult on a perceptual level. Further, inhibition is necessary on a motor level in order to override and prevent the strong response tendency to say the color-word. Stroop interference seems to involve several complex processes including response organization, selection, and execution in the presence of competition of relevant and irrelevant stimuli. Cognitive, neuroimaging, and clinical data support the theory that the Stroop effect involves several complex processes (Awh & Gehring, 1999; Baldo et al., 1998; Glaser & Glaser, 1982; O'Leary & Barber, 1993; Pardo et al., 1990; Peterson et al., 1999; Virzi & Egeth, 1985; Zhang et al., 1999). This area of research has supported the existence of inhibitory control in conflict resolution during at least two different stages in processing. An early perceptual stage involving selection of, as well as encoding and processing of specific stimulus features, requires inhibition of irrelevant stimuli. Second, a late motor stage involving appropriate response execution requires inhibition of inappropriate responses.

Stirling (1979) demonstrated evidence for this late-stage inhibition by revealing that response-related distracters caused greater interference than perceptually related distracters. This finding suggested that the Stroop task requires resolution of conflict on primarily a motor level. In contrast, Glaser and Glaser (1982) presented evidence suggesting that inhibitory control was also necessary at an earlier stage of perceptual conflict resolution. Evidence has been provided supporting both an early (perceptual) and a late (motor) component of Stroop interference, suggesting that there are at least two different processes during which inhibitory control and conflict resolution are necessary. However, because these potentially separable constructs are enmeshed within the Stroop task, the ability to use the task to study these specific neurocognitive processes in isolation is limited.

The processes related to the resolution of perceptual and motor conflict have been studied using methods other than the Stroop task. Findings support the existence of two separable processes. For example, Ridderinkhof and van der Molen (1995) investigated interference effects while recording EEG and EMG in a different task during which large letters (global information) were composed of smaller letters (local information). The large and small letters were congruent, incongruent, or neutral. When differences in processing speed of global and local information were controlled, interference effects were found. EEG and EMG data supported the idea that incongruent letters caused perceptual conflict occurring during an early stage of processing. Participants demonstrated an inability to efficiently inhibit the non-relevant stimulus features of the incongruent letters. In contrast, Doehrman et al. (1978) investigated Stroop interference and found results supporting a later stage response competition theory. When problems in cognitive processing are observed, the question arises whether the deficit is due to insufficient motor inhibition or inefficient perceptual inhibition related to response selection at an earlier stage in cognitive processing, or perhaps due to a combination of both aspects.

Although there is evidence supporting separate processes of perceptual and motor inhibition, commonly used tasks do not allow for differential investigation of these processes. It is unclear whether these two processes involve separate, but perhaps overlapping, neural pathways and distinct cognitive resources, such as those involved in action intentional and attentional systems (Heilman et al., 1993), or both involve a unitary inhibitory control system (Barkley, 1997). According to limited capacity resource and additive factors models, if two co-occurring cognitive processes utilize the same resources, more than a simple additive increase in reaction time would be expected because the limited energy pool must be shared by the two cognitive processes (Sergeant, 1996; Sternberg, 1969). Therefore, if perceptual and motor inhibitory control processes use distinct cognitive resources, then the simultaneous use of both should result in merely an additive increase in response time/errors. In contrast, if the two inhibition processes share the same cognitive resources, then a task involving the simultaneous use of both should result in an interaction effect reflecting a much greater increase in response time and/or errors.

The goal of the present experiment was to develop a set of tasks to assess what are hypothesized to be two separable inhibition processes necessary when there is a perceptual or motor conflict: (1) the inhibition of irrelevant stimulus characteristics and (2) the inhibition of inappropriate motor responses. The tasks were also designed to be independent of verbal ability and to minimize interference effects due to extraneous stimulus-response modality conflicts (Virzi & Egeth, 1985). We hypothesized that the construct of inhibitory control can be divided into that involved with either perceptual/attentional or motor/intentional conflict and that the two processes are independent and involve separate cognitive resources; therefore, we predicted significant effects for both types of conflict without an interaction effect when presented together.

METHOD

Research Participants

Forty-eight undergraduate students (22 males, 26 females) from Queens College of the City University of New York participated in the study. Of the 48 participants, 42 were right-handed, 3 left-handed, and 3 ambidextrous. The majority of the participants were recruited through the Psychology Department Subject Pool and participated to fulfill an introductory psychology course research requirement. A small number of students participated in response to fliers about the study posted on campus and did not receive research credit. The study was approved by the Queens College Institutional Review Board and informed consent was obtained from all participants prior to participation in the study.

Participants ranged in age from 18 to 43 years ($M = 23.3$ years, $SD = 5.9$ years) and ranged in education level from 12 to 18 years, with the majority of participants having completed one year of college. The mean IQ (SD), as estimated using the Vocabulary and Block Design subtests of the Wechsler Adult Intelligence Scale–Third edition (Wechsler, 1997), was 103.6 (12.7).

Measures

Perceptual and motor conflict tasks

This set of computerized tasks (6 subtests) is designed to evaluate the ability to inhibit inappropriate motor responses and/or ignore irrelevant stimulus characteristics. Responses are made using either a left ("z") or right ("/") response key located on a standard keyboard. Since the trials are randomized in terms of right/left responses, handedness should not affect performance on the tasks. At the beginning of each block of trials, participants are reminded to respond as quickly as possible while trying not to make mistakes.

Perceptual conflict (subtests 1–3). The first three subtests are designed to assess perceptual inhibition. Subtest 1 involves 40 randomized trials in which a left- (20 trials) or right- (20 trials) pointing arrow appears in the middle of the screen. The participant is instructed to press either the left or right key on the keyboard depending upon where the arrow is pointing. Subtest 2 involves 40 trials in which a rectangular box appears randomly either on the left (20 trials) or right (20 trials) side of the computer monitor. The participant is instructed to press the key that is located on the same side as the rectangle. Data from Subtest 2 were not used in analyses; rather, the purpose was to elicit the prepotent response. Subtest 3 consists of 80 randomized trials in which there is a left- (40 trials) or right- (40 trials) pointing arrow that appears randomly on either the left (40 trials) or right (40 trials) side of the monitor. The participant is instructed to ignore the location of the arrow and to press the key that is on the side to which the arrow was pointing. Pilot data (analyzed using a paired-samples t-test) revealed that responses to location were significantly faster ($M = 302$ ms, $SD = 37.4$) than responses to arrow direction ($M = 350$ ms, $SD = 31.9$), $t(9) = 7.09$, $p < .001$, suggesting that location is a more salient stimulus characteristic than arrow direction. Thus, in Subtest 3, the participant is required to inhibit the stronger tendency to respond to the location of the stimulus and instead respond according to the direction of the arrow.

Motor conflict (subtests 4–5). Subtests 4 and 5 are designed to assess response organization and motor aspects of response inhibition. Subtest 4 is identical to Subtest 1 and involves 40 trials in which either a left- (20 trials) or right- (20 trials) pointing arrow appears randomly in the center of the computer monitor. The participant is instructed to press the key that is on the side to which the arrow is pointing. Subtest 5 is similar to the Subtest 4 in that arrows are presented in the center of the monitor; however, the participant is required to press the key that is opposite to where the arrow is pointing. Subtest 5 involves response organization and motor inhibition related to conflicting responses.

Perceptual and motor conflict (subtest 6). Lastly, Subtest 6 involves 80 trials that are randomized so that a total of 20 left arrows appear on the left side, 20 left arrows appear on the right, 20 right arrows appear on the right, and 20 right arrows appear on the left. In Subtest 6, the relevant stimulus is the arrow direction and the participant is instructed to ignore the location of the arrow. Additionally, the participant is instructed to press the key that is opposite of where the arrow is pointing. Thus, Subtest 6 involves both perceptual (ignore location) as well as motor (press opposite side) conflict.

Stroop Color-Word Test (Golden, 1978)

The Stroop Color-Word Test contains three parts which require the participant to rapidly, 1) read color words (i.e., red, blue, green) that are printed in black ink; 2) name the ink color that a series of "x"s is printed in (red, blue, or green ink); 3) name the ink color that an incongruent color word is printed in (i.e., the word blue printed in red ink). The third part of the task requires the participant to respond to the relevant stimulus (the ink color) while ignoring the irrelevant stimulus (the word) and inhibiting the automatized response of reading the word. This task was used as a comparison task to the computerized Perceptual and Motor Conflict Tasks to investigate whether there are similarities among the tasks. Stroop interference T scores were used in the analyses. Interference scores were calculated using the formula provided in the manual that accounts for baseline color naming and word reading speeds. A lower interference T score indicates greater interference.

Design/Procedure

All participants completed the tasks in the following fixed order: the computerized Perceptual Conflict (Subtests 1–3), the Vocabulary and Block Design WAIS–III subtests, the computerized Motor Conflict (Subtests 4–5), the computerized Combined Perceptual and Motor Conflict (Subtest 6), and the Stroop Color-Word Test. The WAIS–III subtests were administered between the Perceptual and Motor Conflict tasks in order to give the participants a break from the computerized tasks in order to limit possible vigilance effects.

Reaction time (RT) data from correct arrow trials were analyzed using a 2 (Perceptual Conflict) × 2 (Motor Conflict) repeated measures factorial ANOVA. The two within-group variables were Perceptual and Motor Conflict, each with two levels, either the presence or absence of a conflict (see Figure 1 for specific subtest trials used in calculating mean reaction times for data analyses).

RESULTS

Reaction Time Analyses

Of the 48 participants, data from one male and one female were not available due to computer difficulties. Additionally, two participants exhibited a high number of errors (>20%) on one or more of the conditions; therefore, these data were excluded from the analyses. RT analyses were conducted on the data from the remaining 44 participants. Mean reaction times were calculated in milliseconds (ms) for all conditions. Overall accuracy on all tasks was quite high ($M = 96\%$ correct, $SD = 0.04$) with individual accuracy on each conflict condition greater than 80%. Further, there was no evidence of a speed accuracy tradeoff, such that there was not a significant inverse correlation between RT and errors on any of the tasks ($p > .10$).

Results from the 2 × 2 repeated measures factorial ANOVA revealed a significant Perceptual Conflict main effect, $F(1,43) = 119.28$, $p < .001$, characterized by faster RT in the absence of a perceptual conflict ($M = 422.7$ ms, $SD = 74.8$) than in the presence of a conflict ($M = 593.1$ ms, $SD = 151.2$). Similarly, a Motor Conflict main effect was significant, $F(1,43) = 35.41$, $p < .001$, such that participants responded more quickly when there was not a motor conflict ($M = 450.7$ ms, $SD = 72.5$) than when there was a motor conflict ($M = 565.2$ ms, $SD = 161.2$). Importantly, there was not an interaction effect between Perceptual Conflict and Motor Conflict, $F(1,43) = .08$, $p > .50$ (see Figure 2).

Because correlational analyses (see Secondary Correlational Analyses section) revealed significant correlations between all conflict conditions and Block Design subtest performance, a *post hoc* 2 (Perceptual Conflict) × 2 (Motor Conflict) repeated measures factorial ANCOVA controlling for Block Design subtest performance was conducted. Results were virtually identical to those of the initial analyses. Significant main effects were found for Perceptual Conflict, $F(1,42) = 20.37$, $p < .001$, and Motor Conflict, $F(1,42) = 13.86$, $p = .001$. There was also no significant Perceptual × Motor Conflict interaction, $F(1,42) = .06$, $p > .10$.

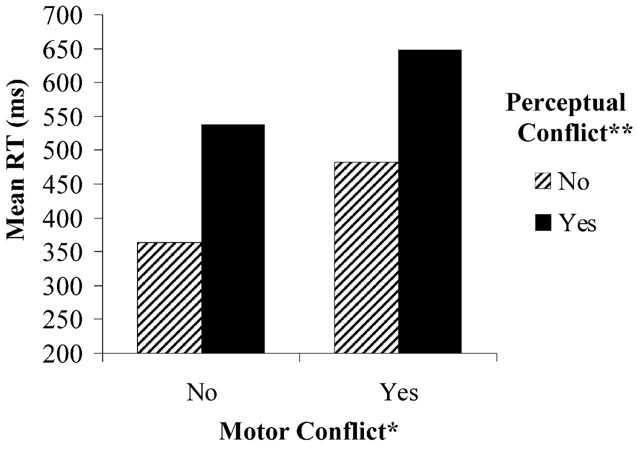

Fig. 2. Mean RT as a Function of Perceptual and Motor Conflict. Participants performed significantly faster in the absence of a conflict across domains. There is no significant Perceptual by Motor Conflict effect. *Main effect, $F(1,43) = 35.41$, $p < .001$; **Main effect, $F(1,43) = 119.28$, p, $< .001$

Secondary Correlational Analyses

Pearson Product Moment Correlations were used to examine relationships between Conflict conditions, baseline RT (no conflict condition), Vocabulary and Block Design subtest performance. Baseline RT and Block Design subtest performance were moderately correlated ($r = -.34$, $p < .05$) such that slower RT was associated with poorer Block Design performance. Results also revealed that all Conflict conditions were significantly correlated with baseline RT and Block Design subtest performance (all $p < .01$) but not

		Perceptual Conflict	
		No	**Yes**
Motor Conflict	**No**	Subtests 1 & 4: (80 trials) ⬅ or ➡ in Center Compatible response to direction	Subtest 3: (40 trials) ➡ on Left, or ⬅ on Right Compatible response to direction
	Yes	Subtest 5: (40 trials) ⬅ or ➡ in Center Incompatible response to direction	Subtest 6: (40 trials) ➡ on Left, or ⬅ on Right Incompatible response to direction & location

Fig. 1. Specific subtest trials used in calculating mean reaction times for data analyses.

with Vocabulary subtest performance ($p > .10$). Therefore, partial correlations controlling for baseline RT and Block Design subtest scores were used to examine the relationship between the different Conflict conditions and Stroop interference. Analyses revealed a significant association between the Perceptual and Motor Conflict interference scores ($r = .47$, $p < .01$). Perceptual Conflict interference was also moderately correlated with Stroop interference scores ($r = -.38$, $p = .013$) such that more Stroop interference (indicated by a lower T score) was associated with more Perceptual Conflict interference (indicated by a higher RT). Motor Conflict interference was not significantly correlated with Stroop interference ($r = -.17$, $p > .10$).

DISCUSSION

Robust main effects for both Perceptual and Motor Conflicts were revealed, such that RT significantly increased in the presence of each type of conflict. The increased RT during the conflict conditions indirectly suggests an increase in cognitive resource load, likely resulting from greater processing complexity. These findings are consistent with those of past studies involving response organization, selection, and execution in the presence of conflicting stimuli and responses (e.g., Baldo et al., 1998). The increased RT observed during the Perceptual Conflict subtests was similar to Glaser and Glaser's (1982) findings that supported the existence of an early stage perceptual inhibition; whereas, the increased RT in the Motor Conflict task supported suggestion of a later stage motor inhibition (e.g., Stirling, 1979).

As predicted, there was not a significant Perceptual Conflict by Motor Conflict interaction effect. This suggests that the two tasks are separable processes that utilize distinct cognitive resource pools. Theoretically, according to limited-capacity resource models, if both of the tasks were not separable and used shared resources, then a significant interaction, indicating more than a simple additive increase in RT would have been apparent in the condition requiring the simultaneous processing of both tasks (e.g., Sergeant, 1996; Sternberg, 1969).

While these data cannot elucidate the distinct neural pathways associated with perceptual and motor conflict, these findings and concepts closely parallel those of Heilman et al. (1993), who describe distinct attentional and action intentional systems. According to their model, the attention-arousal system is mediated primarily through noradrenergic and cholinergic neural systems ascending from brainstem structures. In contrast, the action-intentional system involves dopaminergic pathways ascending from midbrain structures to the prefrontal regions.

Although the lack of a significant perceptual by motor interaction suggests that the Perceptual and Motor Conflict Tasks involve separable processes and resources, the tasks were significantly correlated. This is not likely explained by a visuospatial or visuoperceptual processing requirement because Block Design performance was controlled for in the correlational analyses. Of note, baseline RT (in the absence of conflict) was also moderately correlated with Block Design performance, raising the possibility that there may also be a general speed factor involved. Nevertheless, baseline RT was also controlled for in the analyses. Perhaps there may be a central inhibitory function fundamental to both inhibitory systems described previously (Barkley, 1997). Alternatively, it may be that the two processes use similar resources, but at temporally distinct stages.

The lack of a significant correlation between any of the Conflict tasks and Vocabulary subtest performance suggests that task interference is independent of verbal ability. Performance on each Conflict condition was correlated with Block Design subtest performance, suggesting that the tasks involve a visuospatial component. Perceptual Conflict was moderately correlated with Stroop interference. However, Motor Conflict was not correlated with Stroop interference. Taken together, these findings suggest that the Stroop task taps into perceptual inhibitory processing more than motor inhibitory processing. These data suggest that the Perceptual and Motor Conflict Tasks may be used to assess each type of processing in isolation as well as in combination, while the Stroop task is limited.

One potential weakness of the present study was the lack of counterbalancing of task order. However, the fact that there was no significant difference ($p > .10$) in reaction time to the identical non-conflict task ("press where the arrow is pointing") used in the perceptual and motor inhibition conditions, suggests that order effects were likely minimal if at all present.

In conclusion, efficient cognitive functioning requires both early perceptual inhibition to prevent the interfering effect of irrelevant stimuli and later motor inhibition to prevent execution of inappropriate responses. The primary goal of the present experiment was to develop a set of tasks to assess what were hypothesized to be two separable types of inhibitory control processes. The tasks were designed to evaluate processes of inhibitory control in the presence of a perceptual and/or motor conflict. Further, the study examined whether perceptual and motor inhibition involve different cognitive resources. The computerized tasks were designed so that performance would be independent of verbal ability, which has been found to alter the interference effect (Bahri & Bendania, 1997). Additionally, the tasks were structured to minimize interference effects due to extraneous stimulus-response modality conflicts (Virzi & Egeth, 1985).

Results from the current study support the hypothesis that the construct of inhibition is divisible into that involved in either perceptual or motor conflict resolution. The computerized Perceptual and Motor Conflict Tasks appear to allow differential assessment of early perceptual and late motor inhibition. Further, data support the hypothesis that these processes likely utilize distinct cognitive resources and are independent of verbal ability. Finally, Stroop interference was moderately correlated with performance on the Perceptual Conflict task, but the Motor Conflict task was not. Together, these findings suggest that the Conflict tasks involve greater differentiation of aspects involved in the Stroop task. Used in conjunction with functional imaging techniques, the conflict task may be useful in determining whether perceptual and motor inhibition involve distinct neuroanatomical substrates. The Conflict tasks may also have application in differential evaluation perceptual and motor inhibition abilities within various clinical populations.

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