Dissociating Stimulus-Stimulus and Response-Response Effects in the Stroop Task

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Canadian Journal of Experimental Psychology (in press)

Abstract

The separate semantic and response competition interactions between colour and word processing in a manual Stroop task were evaluated by comparing three trial types. Identity trials are both semantically compatible and response compatible (e.g., BLUE in the colour blue), different response trials are both semantically incompatible and response incompatible (e.g., BLUE in the colour green, where blue and green have different response keys), and same response trials are semantically incompatible and response compatible (e.g., the word BLUE in the colour red, where blue and red have the same key press response). Ink colours were embedded in two different word types, colour words and colour associates. The results using colour words replicated the findings of De Houwer (2003) and demonstrated both a semantic effect (a difference between same response trials and identity trials) and response competition (a difference between same response trials and different response trials). In contrast, the results using colour associates provided evidence for only a semantic effect. These findings support interpretations of the colour associate Stroop effect that attribute the effect to semantics, but challenge Klein's (1964) response competition account and Sharma and McKenna's (1998) claim that the effect of colour associates is dependent on verbal responding. The results confirm that the Stroop colour-word task appears to involve at least two mechanisms, a semantic mechanism and a response competition mechanism.

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The Stroop colour-word task examines speeded performance (usually naming) of an ink colour (the target dimension) embedded within a printed word which itself typically spells out a colour word (the distracter dimension). When the ink colour and colour word mismatch (e.g., BLUE in green ink; $\text{BLUE}_{\text{green}}$) response latencies are slower compared to when the ink colour and colour word match (e.g., $\text{BLUE}_{\text{blue}}$; Stroop, 1935; see MacLeod, 1991, for a review). The Stroop effect has often been cited as evidence for the automaticity of reading and how it interferes with other ongoing cognitive processes. The substantial literature generated in the study of the Stroop effect has shown that the mechanism of interference is quite complex. In particular, much debate has centered on whether this effect is attributable to semantic input effects, response output effects, or a combination of the two (e.g., De Houwer, 2003).

The different effects observed in the Stroop task have been described with reference to the relative compatibility or incompatibility of stimulus and response sets (Kornblum & Lee, 1995; Kornblum, Stevens, Whipple, & Requin, 1999; Zhang & Kornblum, 1998; Zhang, Zhang, and Kornblum, 1999). The stimulus sets can be divided into the relevant stimulus set (the set of all target stimuli) and the irrelevant stimulus set (the set of all distracter stimuli). When the two stimulus sets overlap semantically (as colour words and ink colours do), then the target and distracter can either mismatch and be stimulus-stimulus (SS)-incompatible (e.g., $\text{BLUE}_{\text{green}}$) or match and be SS-compatible (e.g., $\text{BLUE}_{\text{blue}}$). Faster processing of SS-compatible trials over SS-incompatible trials would indicate that input effects or semantics play a role in target processing (Zhang & Kornblum, 1998).

Using a similar line of reasoning, however, the potential responses for the relevant and irrelevant stimulus sets can either match or mismatch. For instance, in a Stroop task involving manual responses, if one colour is assigned to one response key and another colour to another response key, then when a colour word is presented in the incompatible colour there is competition over which key to press (e.g., BLUE_{red}, since blue is assigned to one key and red is assigned to the other key). On the other hand, when a colour word is presented in the compatible colour, there is no competition over which key to press (e.g., $\text{BLUE}_{\text{blue}}$, since both the target and distracter correspond to the same key press response). We call these response-response (RR)-incompatible and RR-compatible trial types, respectively. Faster processing of RR-compatible trials over RR-incompatible trials would indicate that response competition plays a role in target processing.

Elsewhere, RR compatibility has been termed response competition (MacLeod, 1991) or stimulus-response (SR) compatibility (Zhang & Kornblum, 1998). The former terminology is problematic because it only describes incompatible trials. The latter terminology is problematic because the term *SR compatibility* is used in two distinct ways in the Stroop literature. Often, SR compatibility is defined as the strength of the relationship between a stimulus and its assigned or learned response (Simon & Sudalaimuthu, 1979). In other words, the SR effect is defined in terms of the degree to which a given stimulus elicits a given response. In contrast, Kornblum et al. (1998) define SR compatibility as the compatibility of the response the distracter biases with the response for the target. The equivocal use of the term SR compatibility is confusing. It is one thing to speak of the degree to which a stimulus elicits a given response. It is something else entirely to speak of the compatibility of two potential responses. The authors propose that the former effect be termed SR compatibility and the latter effect be termed RR compatibility.

The difficulty of achieving a definitive account of the Stroop effect claiming that the effect is due to semantics (SS), response competition (RR), or a combination of both lies in the fact that SS effects are typically directly confounded with RR effects in the standard Stroop task. For instance, if there are four distracting colour words, four corresponding target ink colours, and four possible responses, one for each colour, then it follows that when the stimulus dimensions are SS-compatible they will also be RR-compatible and that when the stimulus dimensions are SS-incompatible they will also be RR-incompatible. Thus, there are no grounds to claim that one effect occurs to the exclusion of the other.

However, De Houwer (2003) introduced a new variant of the traditional Stroop key press task that convincingly dissociates SS and RR effects. By assigning two colours to one response key (e.g., blue and red) and two more to another key (e.g., green and yellow), three trial types emerge; (1) identity trials, which are both SS-compatible and RR-compatible (e.g., $\text{BLUE}_{\text{blue}}$ or $\text{GREEN}_{\text{green}}$); (2) different response trials, which are both SS-incompatible and RR-incompatible (e.g., $\text{BLUE}_{\text{yellow}}$ or $\text{GREEN}_{\text{red}}$); and (3) same response trials, which are SS-incompatible but RR-compatible, where the target and distracter differ semantically but correspond to the same response (e.g., BLUE_{red} or $\text{GREEN}_{\text{yellow}}$). Using this strategy, De Houwer was able to show that identity trials were faster than same response trials by 28 ms. Given that both of these trial types are RR-compatible, it follows that the difference must be the result of a SS effect. Therefore, this finding validates the claim that SS effects contribute to the Stroop effect. In addition, De Houwer found a 26 ms advantage for same response trials over different response trials. Because both of these trials are SS-incompatible, it follows that this latter difference must be attributable to a RR effect. Thus, both SS and RR effects contribute to the Stroop effect.

In an effort to extend the analysis of the Stroop task using the procedure reported by De Houwer (2003) the current study evaluated the SS and RR effects of another common word type, namely colour associates (e.g., SKY). The effect arising from compatible and incompatible combinations of colour associates and ink colours has been explained in terms of different mechanisms across several reported studies (Glaser & Glaser, 1989; Klein, 1964; MacKinnon, Geiselman, & Woodward, 1985; Majeres, 1974; Posner & Snyder, 1975; Sharma and McKenna, 1998; Stirling, 1979), and the current study permits an examination of these different explanations.

First, the compatibility difference evidenced using colour associate distracters has often been interpreted as being the result of early, semantic processes rather than late, response competition processes (Glaser & Glaser, 1989; MacKinnon, Geiselman, & Woodward, 1985; Stirling, 1979). The reason for interpreting the associate effect in this way is based on the following logic. The two stimulus dimensions are associatively related and the concurrent activation of the word and the target colour ought to produce a SS effect. On the other hand, there does not appear to be a direct RR relationship between the responses for the associate words and the colour responses. The response sets for the target and the distracter are distinct, and therefore no RR effect should be observed. Thus, associates are generally used as a means to present the argument that the Stroop effect results, in whole or in part, from early, semantic processes. If this interpretation is accurate then a straightforward prediction using the procedure reported by De Houwer (2003) can be made. Colour associate distracters should yield a difference between identity and same response trials (i.e., a SS effect) but no difference between same response and different response trials (i.e., a RR effect).

Second, not all researchers accept the early, semantic account of the colour associate effect (Klein, 1964; Posner & Snyder, 1975). Klein suggested that associates may have their effect at output by indirectly producing the colour response linked to the colour associate. Thus, when SKY is presented in the colour green, both blue and green are generated as potential responses and response competition results. According to this account then, associates should produce a RR effect (a difference between same response and different response trials) rather than a SS effect (a difference between identity and same response trials).

Finally, Sharma and McKenna (1998; see also Majeres, 1974) argued that the effects of associates are located in the lexicon (rather than semantic memory) and emerge as a result of verbal responding. They observed a compatibility effect for colour associates using verbal responding to ink colour but the effect was eliminated when manual key press responses were used (but see Brown & Besner, 2001, for a reanalysis of these data). Sharma and McKenna concluded that the influence of colour associates in the Stroop task is restricted to lexical processing and will not be evident using manual responses because the verbal system does not control motor responses. Based on their findings, the current study should reveal no differences between identity, same response, and different response trials using colour associates as distracters.

A second purpose of the current study was to extend the claim that both SS and RR effects are involved in the Stroop task by including a new manipulation that can demonstrate RR effects in the absence of SS effects. Manipulations of this type have been successfully performed elsewhere (De Jong, Liang, & Lauber, 1994; Kornblum et al., 1999; Zhang & Kornblum, 1998). Zhang and Kornblum presented distracter words both above and below a middle target word. The targets and distracters could be selected from one of two stimulus sets, either colour names or digits. In some blocks, participants gave a mediated verbal response, saying an assigned word from one stimulus set (e.g., digit names) in response to a target from the opposite stimulus set (e.g., colour names). For example, if a participant was required to say “six” in response to the target RED, then the distracter SIX would be RR-compatible and the distracter TWO would be

RR-incompatible. Zhang and Kornblum found an advantage for RR-compatible trials over RR-incompatible trials, and they concluded that RR effects could be demonstrated within a Stroop-like task in the absence of SS effects. However, it is not clear from this study whether the results were dependent on the verbal mediation or translation of responses that occurred in this particular task. Other researchers (De Jong et al., 1994; Kornblum et al., 1999) have found RR effects using left-or-right key press responses that combined a spatial location distracter manipulation. For instance, De Jong and colleagues had participants respond to ink colours that were presented on the left or right half of the screen. When the left key was the correct response for a blue stimulus, then a blue colour block presented on the left half of the screen was defined as RR-compatible, whereas a blue colour block presented on the right half of the screen was RR-incompatible. De Jong et al. found that RR-compatible trials were faster than RR-incompatible trials. Although there is no verbal mediation involved in this task, the advantage for RR-compatible over RR-incompatible trials may, in this case, have been due to the introduction of a spatial location distracter to the task as opposed to the typical situation in the Stroop task where interference arises from a colour embedded in a word.

In the current study, we implemented a manipulation that could examine a RR effect in the absence of a SS effect, which relies on the meaning of the distracter word and its compatibility with a left-or-right key press response rather than using a separate spatial manipulation and/or requiring a mediated verbal response. We included direction word distracters (LEFT, RIGHT, EAST, and WEST) and relied on the association of the meaning of the words with either the left or right key press. For instance, if the colour blue is mapped to the left response key, then the distracter words LEFT and WEST are compatible, whereas the distracter words RIGHT and EAST are incompatible.

The direction words are unrelated to ink colour (SS-unrelated), but should have a RR effect because they are SR-compatible with the key press responses. SR effects are well researched in the literature (Fitts & Deininger, 1954; Green & Barber, 1981; Simon & Sudalaimuthu, 1979) and speak to the relationship between a stimulus and its assigned or learned response. In the current task, there is no SR relationship between colours and keys, because the colour-to-key mappings are arbitrary. Direction words, in contrast, should be sufficiently SR-compatible with left-or-right key press responses to generate the corresponding key press as a potential response, and therefore serve to evaluate RR effects in the absence of SS effects.

In summary, the current study attempts to replicate and extend the analysis of the Stroop effect using the procedure proposed by De Houwer (2003). It is predicted that colour associate distracters will provide evidence of SS compatibility effects but no evidence of RR effects. In addition, direction word distracters should produce a RR compatibility effect.

Method

Participants

Of the 36 participants recruited for the study, 28 were recruited from a pool of participants from introductory psychology courses and received course credit in exchange for participation. The other eight participants were acquaintances of the researchers.

Apparatus

A standard PC was used for stimulus presentation and a keyboard was used for responding. E-Prime software (Psychology Software Tools, 2002) controlled stimulus and response timing.

Materials and Design

Forty-eight experimental stimuli were used, consisting of four colour words (BLUE, GREEN, YELLOW, RED), four colour associates (SKY, MONEY, CANARY, FIRE), and four direction words (LEFT, RIGHT, EAST, WEST) presented in each of four ink colours (blue, green, yellow, red). The words were presented in bold, all-capitals, 18-point Courier New font on a blank screen. The words subtended approximately 1.1° visual angle vertically and between 3.0° and 5.9° horizontally, depending on the distracter word. The RGB values for the stimulus colours were 255,0,0 (red); 0,255,0 (green); 0,0,255 (blue); and 255,255,0 (yellow).

Procedure

The experiment took place in a dimly lit room. Participants sat approximately 50 cm away from the screen. They were instructed to look at a fixation cross in the centre of the screen before initiating each trial by depressing the spacebar. Participants were instructed to respond to the ink colour of the word by depressing the “c” key in response to two of the colours and the “m” key in response to the other two colours. Assignment of the four colours to the two keys was counterbalanced across participants. They were urged to respond as quickly as possible, allowing for some mistakes.

After pressing the spacebar, the screen went black for 500 ms and was followed by the presentation of the coloured stimulus. Stimuli remained on the screen for 2000 ms or until a response was made. After 2000 ms, “no response detected” was displayed on the screen. After incorrect responses, “incorrect” was displayed.

Participants were first presented with 128 practice trials, divided into 32 randomized blocks of four practice stimuli. The practice stimuli were five X’s presented in one of the four experimental colours. Following practice, participants were presented with 384 experimental trials, divided into eight randomized blocks of the 48 experimental stimuli.

Results

The dependent measures used for analysis were response latencies and error proportions. Any responses above 2,000 ms or below 300 ms were considered spoiled trials and were excluded from analysis. Participants' median correct response latency for each condition was used as a measure of central tendency.

Response latencies for colour words and colour associates are presented in Figure 1. The associates and colour words were submitted to a 2 (distracter type; colour words, associates) X 3 (trial type; identity, same response, different response) ANOVA. There was a main effect for distracter type, $F(1, 35) = 5.237$, $p = .028$, and trial type, $F(2, 70) = 28.852$, $p < .001$. As predicted, the interaction was also significant, $F(2, 70) = 6.206$, $p = .003$. In order to evaluate the source of the interaction, planned comparisons evaluating the differences between identity, same response, and different response trials were performed on each distracter type. Comparisons for colour words revealed that identity trials (528 ms) were faster than same response trials (552 ms), $t(35) = 3.978$, $p < .001$, $SE_{diff} = 6.050$, and different response trials (584 ms) were slower than same response trials, $t(35) = 3.146$, $p = .003$, $SE_{diff} = 10.102$. Comparisons for colour associates revealed that identity trials (534 ms) were faster than same response trials (548 ms), $t(35) = 2.370$, $p = .023$, $SE_{diff} = 5.790$, but different response trials (552 ms) were not significantly slower than same response trials, $t(35) = .812$, $p = .422$, $SE_{diff} = 5.265$.

The response latency data for the direction words were categorized according to their compatibility with the correct key response and analyzed using a *t*-test. Unexpectedly, compatible trials (541 ms) were not significantly faster than incompatible trials (547 ms), $t(35) = 1.559$, $p = .128$, $SE_{diff} = 3.830$.

Error proportions for colour words and associates are presented in Figure 2. In general, error proportions were very low and ranged between .016 and .046. A 2 (distracter type) X 3 (trial type) ANOVA revealed a significant main effect for trial type, $F(2, 70) = 6.962$, $p = .002$, a marginally significant main effect for distracter type, $F(1, 35) = 3.006$, $p = .092$, and a marginally significant interaction, $F(2, 70) = 2.636$, $p = .079$. In order to determine whether any speed-accuracy trade-offs were evident in the data, planned comparisons evaluating the differences between identity, same response, and different response trials were performed on each distracter type. Comparisons for colour words revealed that error proportions for identity trials (.030) were significantly greater than error proportions for same response trials (.016), $t(35) = 2.346$, $p = .025$, $SE_{diff} = .006$, suggesting a potential speed-accuracy trade-off between these two conditions. As expected, there were significantly more errors for different response trials (.046) than same response trials, $t(35) = 4.084$, $p < .001$, $SE_{diff} = .007$. Comparisons for colour associates revealed neither a difference between identity (.039) and same response trials (.031), $t(35) = 1.012$, $p = .319$, $SE_{diff} = .008$, nor a difference between different response (.039) and same response trials, $t(35) = 1.049$, $p = .301$, $SE_{diff} = .008$. Lastly, the planned comparison for the direction associated distracters revealed no difference between RR-compatible (.031) and RR-incompatible trials (.036), $t(35) = .907$, $p = .371$, $SE_{diff} =.006$.

Discussion

The response latency data replicate the results reported by De Houwer (2003), showing that colour word distracters produce both SS and RR effects in the Stroop task involving key press responses. This finding adds further support to the claim that models of the Stroop colour-word task need to incorporate both an input or semantic interference mechanism and a response competition mechanism in order to fully account for the effect.

The critical findings of the current study involve the outcomes for the colour associate distracters. Unlike colour word distracters, the effects of colour associates on performance were restricted to a SS effect. In other words, the current results suggest that colour associates influence ink processing at an early, semantic level and not at a response competition level. These results are in line with previous accounts holding that the effects of colour associate distracters in the Stroop task are semantic in nature (Glaser & Glaser, 1989; MacKinnon, Geiselman, & Woodward, 1985; Stirling, 1979). Such accounts predict a SS effect because the relationship of an associate to an ink colour is one of similarity in meaning, but do not predict a RR effect because there is no direct relationship between the response elicited by an ink colour (in this case, a left or right key press) and the response elicited by a colour associate (in this case, none).

The results, however, present problems for other interpretations that have been offered of the compatibility effect produced by colour associates. First, the current data are incompatible with Klein's (1964) response competition account. According to this account, there should have been a RR, rather than a SS, effect for associates. The current results question the idea that colour associates automatically elicit the response of the associated colour because there was no evidence for a RR effect. Second, the finding of an associate effect using key press responses also contradicts the claim of Sharma and McKenna (1998) that an effect of colour associates should only exist with a verbal response modality, and provides additional support for the position of Brown and Besner (2001). Thus, the claim by Sharma and McKenna that the semantic effects of colour associates are restricted to the lexicon needs to be re-evaluated. Although beyond the scope of this paper, the true locus of the associate effect may be in semantic memory. Alternatively, there may be a similar effect which occurs in both semantic memory and the lexicon.

The manipulation made in order to isolate RR effects was unsuccessful. The difference between RR-compatible and RR-incompatible trials was non-significant for both the response latency and error proportion data. Given that participants were using the index fingers on their left and right hands to press a left or right key, it was anticipated that direction words such as LEFT or RIGHT would be able to generate the response tendencies related to their meanings (i.e., a left or right key press, respectively). This failure to find an effect may indicate that the RR effect is dependent on verbal mediation or spatial location as discussed previously, but a more reasonable explanation is that the SR relationship between the meaning of the direction words and the key press responses was simply too weak. Zhang and Kornblum (1998) were successful in eliciting RR effects by using distracter words that either matched or mismatched the verbal response required for the target. The SR compatibility of a word with its pronunciation is clearly stronger than the SR compatibility between a direction word and a key press response. In order for direction words to prime motor responses, the processed direction word information has to undergo significant translation before it generates a motor representation. Thus, the apparent incongruence of the current results with past findings may simply reflect the varying effectiveness of the different manipulations used. If so, then the manipulations attempted here should be successful if the relation between the direction words and the key press responses is strengthened. For instance, if one were to have a certain proportion of trials in which participants are required to respond to the word instead of the colour, then the relationship between a direction associate and its corresponding key should be strengthened, and the suggested RR effect should be obtained.

The Stroop colour-word task is widely used as a convenient tool to measure the influence of so-called automatic reading processes on other simultaneous cognitive processing. A longstanding debate has centred on determining whether this important task can be modelled using a single locus of colour and word interaction, usually in terms of some form of response competition mechanism. The current results suggest that the description of the task using a single locus is too simplistic, and future attempts to successfully model the task should concentrate on at least two mechanisms, a semantic/lexical based mechanism and a response competition based mechanism.

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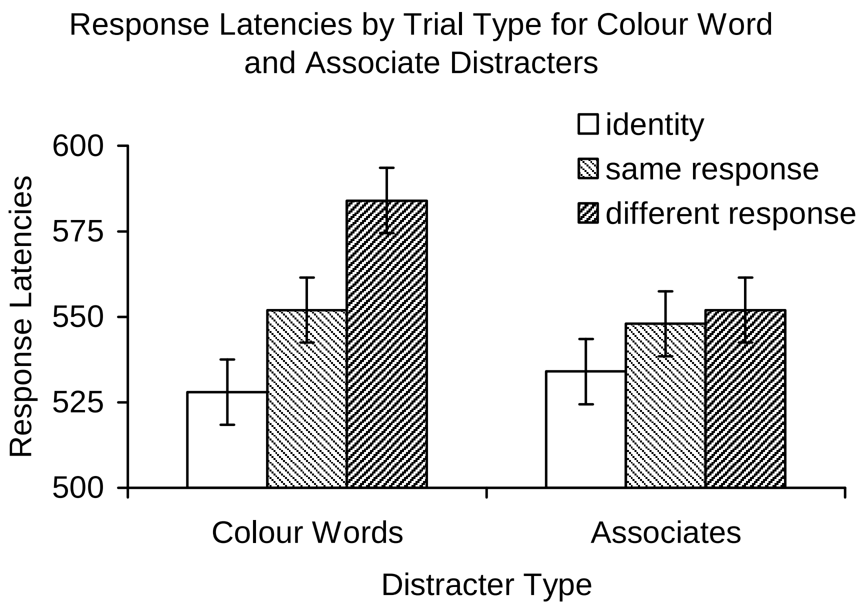

Figure 1. Response latencies in milliseconds for the three trial types for colour word and associate distracters. Error bars represent the 95% confidence interval for within-group designs, calculated with the formula described by Loftus and Masson (1994; see also Masson & Loftus, 2003).

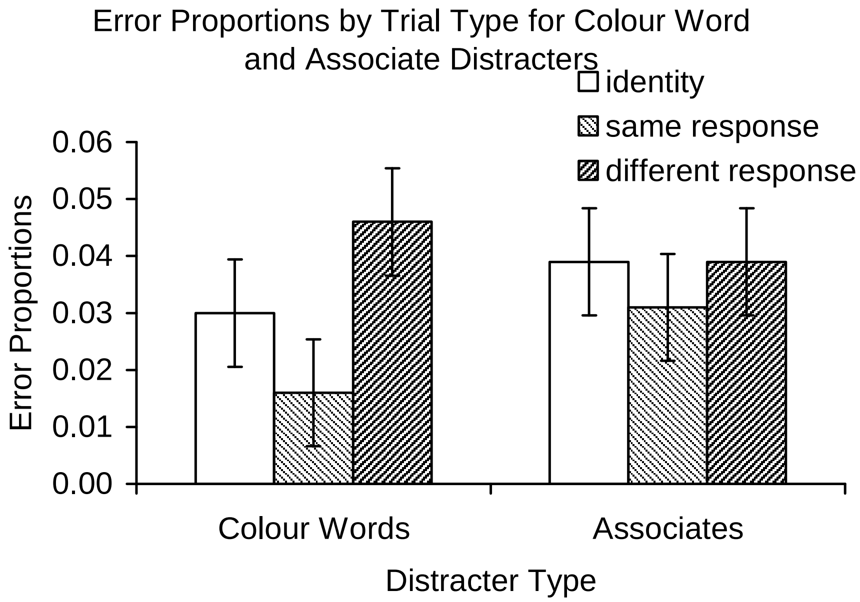

Figure 2. Error proportions for the three trial types for colour word and associate distracters. Error bars represent the 95% confidence interval for within-group designs, calculated with the formula described by Loftus and Masson (1994; see also Masson & Loftus, 2003).