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Filling a Gap in the Semantic Gradient: Color Associates and Response Set Effects in the Stroop Task

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Abstract

In the Stroop task, incongruent color associates (e.g., LAKE) interfere more with color identification than neutral words (e.g., SEAT). However, in past studies color associates were related to colors in the response set. Response set membership is an important factor in Stroop interference, because color words in the response set interfere more than color words not in the response set. It has not been established whether response set membership plays a role in the ability of a color *associate* to interfere with color identification. This issue was addressed in two experiments (one using vocal responses and one using manual responses) by comparing the magnitude of interference caused by color associates related to colors in the response set with color associates unrelated to colors in the response set. The results of both experiments show that color associates unrelated to colors in the response set interfered with color identification more than neutral words. However, the amount of interference was less than that from color associates that were related to colors in the response set. In addition, this pattern was consistent across response modality. These results are discussed with respect to various theoretical accounts of Stroop interference.

Filling a Gap in the Semantic Gradient:

Color Associates and Response Set in the Stroop Task

The Stroop task (Stroop, 1935) and its many variants are a fixture in the cognitive psychology literature. This task typically involves the identification of the display color of an incongruent color word (e.g., the word BLUE displayed in red), which leads to slower responding relative to the identification of the display color of a neutral stimulus such as a color patch or a neutral word (e.g., the word SEAT in red). The Stroop effect is robust and well documented (see MacLeod, 1991, for a review). The present investigation examines one variant of the Stroop effect wherein words associated to color words (e.g., LAKE) interfere with color identification.

Klein (1964) measured the amount of interference caused by different types of stimuli in a Stroop color-naming task. He reported a “semantic gradient” in which interference increased as a function of the relation between the word and color: (1) color associates (e.g., LAKE) produced more interference than neutral words (e.g., SEAT), (2) color words not in the response set (e.g., BROWN when the display colors were red/green/blue/yellow) produced more interference than color associates, and (3) color words in the response set produced more interference than color words not in the response set. Thus, as the semantic relationship between the irrelevant word and the display color increased, so did the magnitude of Stroop interference.

The properties of this semantic gradient are of major theoretical interest (see MacLeod, 1991, for a review) and have been systematically investigated (Glaser & Glaser, 1989; Fox, Shor, & Steinman, 1971; Klein, 1964; Proctor, 1978; Schiebe, Shaver, & Carrier, 1967; Sharma & McKenna, 1998). However, there is an empirical gap in this semantic gradient. Specifically, the role of response set membership vis a vis the color associate effect has yet to be systematically investigated. Klein's (1964) results, along with others (Proctor, 1978; Sharma & McKenna, 1998), clearly established a role for response set membership with *color* words. However, no such test has been conducted with color *associates*. Indeed, the research to date has only established that a color associate related to a color *in* the response set will interfere compared to a neutral word (Klein, 1964; Schiebe et al., 1967; Sharma and McKenna, 1998). It has yet to be established whether a color associate unrelated to a color in the response set will interfere compared to a neutral word (e.g., will the word LAKE cause more interference than the word SEAT if the display color blue is *not* in the response set).

The present experiments assess the relative amounts of interference for color associates related to a color in or out of the response set. Vocal responses were used in Experiment 1 and manual responses in Experiment 2. Comparing patterns of Stroop interference across vocal and manual response modalities has long been used as a strategy to constrain theoretical accounts of Stroop interference (see MacLeod, 1991). A number of predictions can be derived from extant accounts of Stroop interference with respect to the effect of response set membership and response modality on the color associate effect.

Roelofs (2003)

A response competition model, the Weaver++ model (Roelofs, 2003), is able to simulate both the previously established color associate effect and the response set membership effect with color words. A color associate can cause response competition by activating a color concept of a potential response via the conceptual network (e.g., the word LAKE is semantically associated with the color concept [blue], so if “blue” is a potential response, then response competition would result).

Response Set Membership and Color Associates

According to Roelofs’ account, color associates related to a response should produce more interference than color associates unrelated to a response, given that the former activates the response related color concept directly. For example, if “blue” is a potential response and “green” is not, the color associate LAKE would activate the concept [blue] and the response “blue” whereas the color associate FROG would activate the concept [green] which in turn would have to activate other color concepts (e.g., [red], [blue]) in order to produce response competition. Thus, this model predicts a response set membership effect for color associates (i.e., color associates related to a potential response should interfere more than color associates unrelated to potential response). Further, color associates unrelated to a response should produce more interference than neutral words because neutral words (e.g., SEAT) do not activate color concepts.

Vocal vs. Manual Responding

Roelofs’ model predicts the same outcome for vocal and manual responses provided one assumes that the latter are lexically mediated: *“Stroop interference lies within the language production system. Interference should remain if lexical entries are needed to mediate a button press response”* (p. 115). This assumption implies that response type, when no effort has been made to rule out lexical mediation, should produce the same qualitative pattern of interference. Critically, this is not always true. For example, vocal but not manual responses yield a “lexical” effect (i.e., neutral words interfere more than consonant letter strings; Sharma & McKenna, 1998). In addition, manual responses but not vocal responses yield a Reverse Stroop effect (i.e., the display color interferes with word identification; Blais & Besner, 2004). Thus, vocal and manual responses do not always produce the same qualitative pattern of interference. Given these results it is important to note that if lexical mediation is not assumed then Roelofs' (2003) model predicts a response set membership effect for color associates when vocal responses are used but no color associate effect when manual responses are used.

Sharma and McKenna (1998)

Sharma and McKenna proposed two stages at which Stroop interference could arise – a lexical stage and a response selection stage. In their account, which is based largely on the Glaser and Glaser (1989) and Sugg and MacDonald (1994) models, the color associate effect is due to interference at the lexical stage. Color associates produce more competition in the lexicon than neutral words because the former receive activation from both the direct perception of the word and its semantic association with the display color whereas the latter receive activation only from the direct perception of the word. In addition, Sharma and McKenna claim that the response set membership effect with color words is due to interference at the response selection stage. Color words in the response set can activate competing responses via an identity code.

Response Set Membership and Color Associates

According to Sharma and McKenna's account, the color associate effect should not be modulated by whether the color associate is related to a color in the response set or not. Color associates, at least here, are never identical to a response (i.e., the response is never "lake") and therefore should be unable to produce response competition via an identity code. Therefore, the amount of interference from color associates related or unrelated to a potential response should not differ, but both should interfere more than neutral words.

Vocal vs. Manual Responses

In addition, Sharma and McKenna's account explicitly assumes that manual responses do *not* have "privileged" access to the lexical stage. In contrast, both vocal and manual responses have access to the response selection stage. Thus, effects claimed to be due to interference at the lexical stage (e.g., the color associate effect) should be present with vocal but not manual responses (but see Brown and Besner, 2001).

Schmidt and Cheesman (2005)

Another multiple stage account claims that Stroop interference is due to both stimulus conflict and response conflict (see also De Houwer, 2003; Zhang & Kornblum, 1998; Zhang, Zhang, & Kornblum, 1999). Stimulus conflict is interference that occurs during stimulus processing (see De Houwer, 2003; Klopfer, 1996; Seymour, 1977; Zhang & Kornblum, 1998; Zhang, Zhang & Kornblum, 1999) and response conflict occurs during response selection (see Cohen, Dunbar & McClelland, 1990; Roelofs, 2003). Schmidt and Cheesman (2005) concluded that the color associate Stroop effect was due to stimulus conflict and not response conflict (e.g., the word LAKE would activate the color concept [blue] and this would interfere with the conceptual encoding of the correct display color on incongruent trials).

Response Set Membership and Color Associates

Color associates will activate color concepts in semantics regardless of whether they are related or unrelated to potential responses. Thus, the stimulus conflict account of the color associate effect predicts interference, relative to neutral trials which do not activate color concepts, in both these conditions. This account makes no explicit prediction about the *amount* of interference for color associates related versus unrelated to a response. It only predicts that both such associates should interfere more than neutral words.

Vocal vs. Manual Responses

Stimulus conflict occurs at an early processing stage (semantics) for both vocal and manual responses. Both De Houwer (2003) and Schmidt and Cheesman (2005) have demonstrated stimulus conflicts effects with manual responses, the latter with color associates, and Zhang and Kornblum (1998) have demonstrated stimulus conflict effects with vocal responses. Therefore any observed effects should be *independent* of response modality.

Summary

Roelofs' (2003) model predicts that color associates related to a potential response will interfere more than color associates unrelated to a potential response and the latter will interfere more than neutral words. This response set membership effect with color associates should also be independent of response modality as long as one assumes that manual responses are lexically mediated.

Sharma and McKenna's (1998) two-stage model of vocal and manual Stroop interference predicts that whether a color associate is related to a response or not should not matter, both should produce interference relative to a neutral word. In addition, there should be no color associate effect with *manual* responses.

Lastly, Schmidt and Cheesman's (2005) stimulus conflict account predicts that color associates related and unrelated to potential responses should interfere more than neutral items. This effect should also be independent of response modality.

Method

Participants

One hundred and thirty-two (30 in Experiment 1 and 112 in Experiment 2) University of Waterloo undergraduates participated in exchange for $4 each. All participants reported normal or corrected-to-normal vision and spoke English as a first language.

Apparatus

Stimuli were presented on a 17-inch ADI color monitor. Stimulus presentation and response collection were controlled by E-Prime software (Psychology Software Tools, 2002). Vocal responses were collected by a headset microphone. Manual responses were made on a standard QWERTY keyboard.

Stimuli

The fixation marker, either a + or -, was presented in white and subtended 2° horizontally and vertically. Eight different display colors were used (red/green/blue values in E-Prime): white (255, 255, 255), orange (255, 153, 0), blue (0, 0, 255), green (0, 255, 0), brown (123, 71, 20), yellow (255, 255, 0), grey (155, 155, 155), and red (255, 0, 0). Display colors were separated into two sets of four (white/orange/blue/green and brown/yellow/grey/red). Half the subjects received the first set and the remaining participants received the second set.

Sixteen upper case Arial font words were used and were presented at the center of a black screen. Words were 4 or 7 letters subtending 3° and 5° of visual angle horizontally, respectively, and 1° of visual angle vertically. Eight color-associated words (selected mainly from previous studies), one for each display color, and eight color-unrelated neutral words were selected. Neutral words were matched for length, number of syllables, and approximate frequency with one of the color associates. Color associates and neutral words did not share their first letter with any of the display colors (see the Appendix for the stimulus set).

Each participant saw all of the words. Because each participant only received four of the eight display colors, half the color associates were related to a color in the response set and half the color associates were unrelated to a color in the response set.

Color associates unrelated to a color in the response set, by definition, cannot be displayed in a congruent display color. We therefore eliminated congruent trials from the design. Each color associate related to a color in the response set and its matched neutral word was paired with a color associate unrelated to a color in the response set and its matched neutral word (e.g., FROG-KITE and LIPS-FOOT; see Appendix) and all four of these stimuli appeared in the remaining three display colors. Apart from these restrictions all stimuli appeared an equal number of times in each of the display colors.

Design

A 3 (trial type; color associate related to a color in the response set, color associate unrelated to a color in the response set, neutral) factor within subject design was used in both experiments.

Procedure

Participants were seated approximately 60 cm from the computer monitor. Each trial began with the presentation of a fixation marker (+ or -) in the center of the screen. Participants initiated the trial by pressing the spacebar. A blank screen was then presented for 500 ms after which the colored word appeared at fixation.

In Experiment 1 participants were asked to name the display color of the word aloud quickly and accurately. After the participant's response the experimenter keyed in their accuracy.

In Experiment 2 participants were asked to press a key associated with the display color as quickly and accurately as possible. The S, D, K, and L keys were used as responses and each key was assigned to each color response an equal number of times across participants. Keys were not labeled.

After a response or 2000 ms a blank screen was presented for 1000 ms followed by the next fixation. The fixation was a + if the response on the previous trial was correct and a – otherwise. Participants performed one block of 48 practice trials and eight blocks of 48 experiment trials.

Results

Spoiled trials (microphone errors, timeouts, and responses < 200 ms; 3.5% in Experiment 1 and 0.6% in Experiment 2) and errors (0.1% in Experiment 1 and 3.6% in Experiment 2) were removed before RT analysis. The remaining data were subjected to a recursive trimming procedure that removed outliers (1.4% of the raw data in Experiment 1 and 2.7% in Experiment 2) based on a criterion cut-off set independently for each participant in each condition by reference to the sample size and the standard deviation in that condition (Van Selst & Jolicœur, 1994). Results from Experiments 1 and 2 are presented in Figure 1.

Experiment 1: Vocal

The main effect of trial type was significant, $F(2, 58) = 16.90$, $MSE = 164.75$, $p < .001$. Responses to color associates related to a color in the response set (651 ms) were slower than responses to color associates unrelated to a color in the response set (643 ms), $t\ (29) = 2.33$, $SEM = 3.52$, $p < .05$. In addition, responses to color associates unrelated to a color in the response set were slower than responses to neutral words (632 ms), $t\ (29) = 4.04$, $SEM = 2.72$, $p < .05$. Errors were committed on less than 1% of the trials so no error analysis was conducted.

Experiment 2: Manual

The main effect of trial type was significant, $F\ (2, 222) = 8.32$, $MSE = 537.63$, $p < .001$. Results were consistent with Experiment 1. Responses to color associates related to a color in the response set (647 ms) were slower than responses to color associates unrelated to a color in the response set (641 ms), $t\ (111) = 1.74$, $SEM = 3.38$, $p < .05$ one tailed, and responses to color associates unrelated to a color in the response set were slower than responses to neutral words (634 ms), $t\ (111) = 2.39$, $SEM = 2.82$, $p < .05$. Nothing in the error data contradicted the interpretation of the RTs.

Discussion

The experiments have produced three findings. First, color associates related to a color in the response set interfered more than color associates unrelated to a color in the response set. Second, color associates unrelated to a color in the response set produced more interference than neutral words. Finally, these effects were observed for both vocal and manual responses. None of these effects have been reported previously. We turn now to a discussion of the theoretical implications of these results.

Roelofs (2003)

Roelofs' response competition model correctly predicted the ordinal relation between the three conditions. In addition, Roelofs' model can also account for the consistency across response modality, provided it is assumed that manual responses are lexically mediated. However, as noted earlier there is evidence inconsistent with this assumption (Blais & Besner, 2004; Sharma & McKenna, 1998).

Sharma and McKenna (1998)

The present results are inconsistent with the predictions from Sharma and McKenna's two-stage account of Stroop interference (see also Brown & Besner, 2001). First, their model predicts no response set membership effect with color associates because color associates do not share an identity code with a response. Importantly, the results of the present experiments demonstrate that a subset of the irrelevant stimuli need not be *identical* to a response in order to produce a response set effect (see also Durgin, 2003).

Sharma and McKenna also claimed that manual responses do not have access to the lexical stage at which the color associate effect is claimed to originate. The color associate effect obtained here with manual responses is inconsistent with this claim. Either manual responses have access to the lexical stage or the lexical stage is not where the color associate effect is produced. Our own preference is for the idea that the color associate effect arises in semantics and that manual responses have access to semantic level processing (Brown & Besner, 2001).

Schmidt and Cheesman (2005)

Schmidt and Cheesman argued that the color associate Stroop effect is due to stimulus conflict. This account correctly predicted that color associates related and unrelated to a response produce interference. The fact that these effects were observed across response modality is also consistent with Schmidt and Cheesman's account. However, their stimulus conflict account makes no explicit prediction regarding the effect of response set membership on the color associate effect. Thus, the present results force a refinement of their account. That is, if the color associate Stroop effect is due to stimulus conflict, then the stage at which this conflict occurs (i.e., semantics) must be sensitive to response set membership. A “priming” process (e.g., Glaser & Glaser, 1989; see also Cohen et al., 1990) may be used to account for response set effects with color associates in this context.

Thus, the present results are consistent with both the Roelofs (2003) and Schmidt and Cheesman (2005) accounts. It is important to note that the two accounts make very different claims regarding (1) the locus of Stroop interference and (2) how semantics produces the color associate effect. In Roelofs' model, interference occurs at a single response selection stage and associates act via a *facilitory* mechanism in semantics that leads to activation of competing responses in the response stage. In Schmidt and Cheesman's account interference is of two types, stimulus conflict and response conflict, and associates act via an *inhibitory* mechanism in semantics that slows conceptual encoding (i.e., a stimulus conflict effect). If both of these accounts can provide explanations for the present results, then one is tempted to prefer the single to the multiple stage account on grounds of parsimony. However, De Houwer (2003) has provided some evidence for the existence of both stimulus and response conflict using a variant of the standard Stroop paradigm. In his paradigm, two ink colors were mapped to one response key (e.g., blue and red to one key and yellow and green to another key) thus producing three conditions: (1) identity trials, in which the irrelevant word is congruent with both the display color and the target response (e.g., the word BLUE in blue), (2) same response trials, in which the irrelevant word is incongruent with the display color but congruent with the target response (e.g., the word BLUE in red), and (3) different response trials, in which the irrelevant word is incongruent with both the display color and the target response (e.g., the word BLUE in green). The stimulus conflict effect was indexed by comparing identity trials to same response trials and the response conflict effect was indexed by comparing different response trials to same response trials.

According to a single stage response competition account like Roelofs' there should be no difference between identity and same response trials (i.e., both signal the same response). However, De Houwer (2003) found that color words produced both a stimulus conflict effect (identity trials were responded to faster than same response trials) and a response conflict effect (same response trials were responded to faster than different response trials). It is unclear how a single stage response competition model would account for these results. The results, however, are consistent with a multiple locus account of Stroop interference. More generally, while single stage response competition accounts have historically been favoured in the Stroop literature (Cohen et al., 1990; Klein, 1964; MacLeod, 1991; Posner & Snyder, 1975; Roelofs, 2003), a number of multi-stage accounts of Stroop interference exist (De Houwer, 2003; Klopfer, 1996; Seymour, 1977; Zhang & Kornblum, 1998; Zhang, Zhang, & Kornblum, 1999) but, to date, have failed to find a receptive audience.

Conclusion

The present investigation provides the first demonstration that associates unrelated to a color in the response set cause interference and also the first demonstration of a response set effect for color associates. Finally, these effects are independent of response modality. The present results thus add to the large body of empirical phenomena associated with the Stroop effect and provide additional constraints on evolving theories of Stroop interference.

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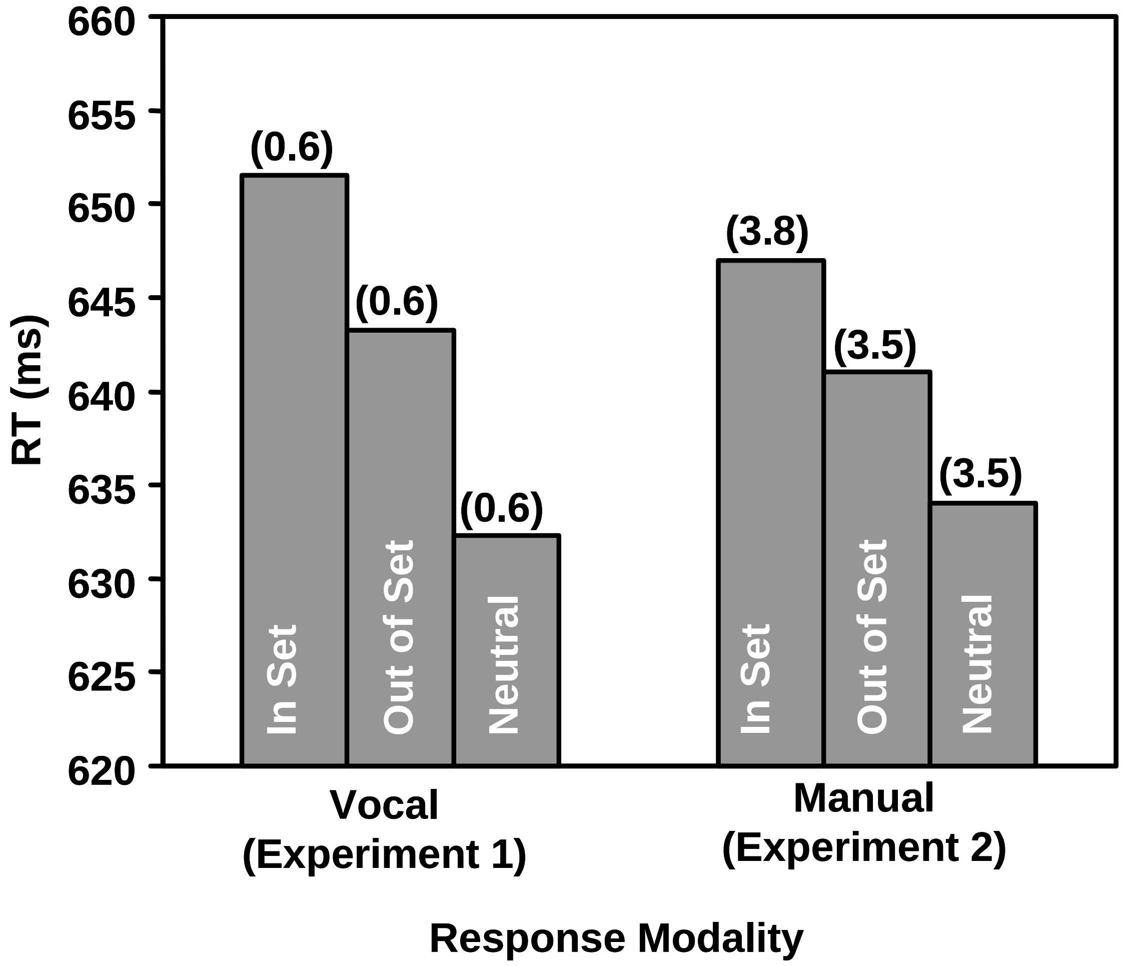
Figure Caption

Figure 1. Mean RTs and percentage error (in brackets) for the three trial types: (1) color associates related to a color in the response set (In Set), (2) color associates unrelated to a color in the response set (Out of Set), and (3) neutral (Neutral), as a function of vocal and manual responses.



660
655
650
645
640
635
630
625
620
RT (ms)
(0.6)
(0.6)
(0.6)
(3.8)
(3.5)
(3.5)
In Set
Out of Set
Neutral
In Set
Out of Set
Neutral
Vocal
(Experiment 1)
Manual
(Experiment 2)
Response Modality

Appendix

Stimulus set for the Experiments 1 and 2. There were two display color groups (white/orange/blue/green and brown/yellow/grey/red) which corresponded to the two stimulus groups (SNOW/PUMPKIN/LAKE/FROG and DIRT/MUSTARD/IRON/LIPS). Each participant received one of the display color groups and the corresponding stimulus group made up the *in response set associates* and the other stimulus group made up the *out of response set associates*. Matched pairs (1-4) never appeared in the display color congruent with the item acting as an in response set associate.

	Stimulus Group 1		Stimulus Group 2	
Matched Pairs	Associate	Neutral Match	Associate	Neutral Match
1	SNOW	MINE	DIRT	TOUR
2	PUMPKIN	INCENSE	MUSTARD	SHERIFF
3	LAKE	SEAT	IRON	COAT
4	FROG	KITE	LIPS	FOOT