You Can't Stroop a Lexical Decision: Is Semantic Processing Fundamentally Facilitative?

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Abstract

It is well documented that related prime words facilitate target processing in lexical decision (e.g., DOCTOR facilitates NURSE), but interfere with target processing in the Stroop task (e.g., the word BLUE slows the time to name the colour RED). Five experiments explored several potential explanations for these differences. In Experiments 1 and 2, all stimuli were novel (as in a typical lexical decision design). Participants were faster both to make lexical decisions and to read colour words aloud that were primed by *incongruent* associates (e.g., BANANA) relative to a neutral prime (e.g., KNOT). Experiments 3 and 4 used a small set of repeatedly-presented stimuli (as in a typical Stroop design). Incongruent colour words facilitated lexical decisions to target colour words, but interfered with identification (reading aloud). Experiment 5 further showed that interference is still observed in identification when the distracter set size is large but the target/response set size is small. These findings are taken to suggest that semantic connections are solely facilitative and that response competition only occurs when there is a small set of repeated responses and identification (rather than lexical decision) is required. The more general problem of research fragmentation is briefly discussed.

You Can't Stroop a Lexical Decision:

Is Semantic Processing Fundamentally Facilitative?

As with any discipline, research fragmentation can be a problem in cognitive psychology. Various fields tend to splinter over time and can often become so isolated from one another that we frequently fail to address obvious questions arising from similar manipulations producing different results across tasks. We investigate one such question here. Specifically, why does the presence of a distracting colour word (e.g., BLACK) *slow* identification of a different print colour (e.g., blue) in the Stroop task, but *speed* judgments of the same colour target (e.g., BLUE) in the lexical decision task? This is not a trivial issue and these types of cross-paradigm comparisons are important (relatedly, see Besner, Davelaar, Alcott, & Parry, 1984). In both literatures (lexical decision and Stroop), researchers are looking to answer the same higher-order questions about semantics (e.g., how it is organised, how one concept activates or affects another, etc.), yet they seem to differ in their answer to one of the most basic questions about the impact of semantically related information on performance (i.e., does it facilitate or interfere?). The work reported here provides some tentative answers to this question.

The Stroop Task

In the Stroop task (Stroop, 1935), participants are presented with a colour word that is displayed in a colour (e.g., BLUE printed in red; BLUE_{red}) and are asked to ignore the word and identify the colour that it is printed in (typically by naming the color or pressing an assigned key). In the typical configuration, there is a small set of distracting words and target colours that appear repeatedly throughout the course of the experiment. For instance, a typical experiment would present the words BLUE, GREEN, RED, and YELLOW repeatedly in each of the colours blue, green, red, and yellow for several hundred trials. The standard finding is that participants are *slower* on incongruent trials (where the word and colour mismatch; e.g., BLUE_{red}) than on congruent trials (where the word and colour match; e.g., RED_{red}) or neutral trials (e.g., $MOVE_{red}$; Dalrymple-Alford & Budayr, 1966; Logan & Zbrodoff, 1979; Schmidt & Besner, 2008; Sichel & Chandler, 1969; see MacLeod, 1991, for a review). This effect has also been observed with colour-associated words (e.g., SKY, which is related in meaning to *blue*). Participants respond slower to incongruent colour associate trials (e.g., SKY_{red}) than to neutral or congruent colour associate trials (e.g., SKY_{blue}; Klein, 1964; Majeres, 1974; Manwell, Roberts, & Besner, 2004; Posner & Snyder, 1975; Risko, Schmidt, & Besner, 2006; Schmidt & Cheesman, 2005; Stirling, 1979).

These *interference* effects have also been observed in word-word versions of the Stroop task, where both the distracter (the prime) and target are words (e.g., the prime word BLUE followed by the target word GREEN; BLUE-GREEN). Participants are *slower* to respond to the target colour words when they are primed with an incongruent colour word or colour associate (e.g., BLUE-GREEN or SKY-RED) relative to a neutral word (e.g., MOVE-GREEN) or a congruent word (e.g., GREEN-GREEN or BLOOD-RED; Glaser & Glaser, 1982, 1989).

Note that the difference in performance between incongruent and neutral trials is typically taken as evidence that different colours *compete* with each other, including in semantics (e.g., Luo, 1999 argues for a semantic competition account of the Stroop). For instance, activation of the *blue* concept leads to inhibition of the other colours. However, an interpretation in terms of semantic facilitation is also possible. If the target and incongruent distracting colours *facilitate* each other at the semantic level, then this will mean that two possible responses corresponding to these colours will be highly activated during the response selection stage (i.e., where conflict *does* occur). This conflict will take some extra time to resolve. Thus, somewhat paradoxically, the fact that *red* and *blue* semantically facilitate each other actually leads to an overall performance *cost*.

The Lexical Decision Task

Participants in the lexical decision task are asked to quickly and accurately determine whether a letter string spells a word that they know (e.g., NURSE) or one that they do not know (a nonword such as NARSE). In a typical lexical decision experiment every word is presented only once. A well-replicated finding in the lexical decision literature, referred to as the semantic priming effect, is the observation that participants are *faster* to make lexical decisions to words that are preceded by a semantically-related prime word (e.g., DOCTOR-NURSE) than by a semantically-unrelated word (e.g., TABLE-NURSE; see reviews by McNamara, 2005; Neely, 1991). There are various procedures for obtaining a semantic priming effect, but it is commonly done by presenting a prime word (e.g., TABLE) followed by a target word (e.g., CHAIR), similar to a word-word Stroop task.

The semantic priming effect is normally demonstrated with direct associates – i.e., prime words that have been shown to have strong forward associations with the target word, such as DOCTOR-NURSE or TABLE-CHAIR. However, indirect (or mediated) associates also produce a semantic priming effect (e.g., LION-STRIPES, where LION is related to TIGER, which is related to STRIPES; Angwin et al., 2004; McNamara & Altarriba, 1988) as do backward-related prime-target pairs (i.e., where the target has a strong association to the prime, but not vice versa; Koriat, 1981; Thomas, Neely, & O'Connor, 2012). Semantic priming is also observed in reading aloud (e.g., Lupker, 1984).

Note that the semantic relationship between a related prime and target is generally assumed to be facilitative. For instance, *tiger* facilitates *stripes.* This is, of course, intuitive and explains the benefit to performance for related relative to unrelated primes in lexical decision.

We already pointed out that interference effects in the Stroop can be explained in terms of facilitation rather than interference. It is not clear that the same can be said for lexical decision. If a related prime (e.g., TIGER) *inhibits* semantically-related target concepts (e.g., STRIPES), then lexical decisions would be impaired relative to the unrelated prime condition where the prime does not inhibit the target. Inhibition of semantically-related concepts simply cannot produce facilitation.

Critical Observations

In the Stroop paradigm, "incongruent" colour word distracters are strong direct associates for the "competing" colours (e.g., BLUE has a strong semantic relationship with *red*) and "incongruent" colour associates are strong indirect associates (e.g., SKY is related to *blue*, which is related to *red*). However, in the Stroop task incongruent colour words (e.g., BLUE_{red}) and incongruent colour associates (SKY_{red}) *interfere* with performance relative to a neutral control. In contrast, in the lexical decision task both direct and indirect associates *facilitate* performance. What accounts for this difference? Why is it the case that semantically-related words aid performance in one context (lexical decision), but impair it in another (Stroop)? The goal of the present work is to systematically investigate these two paradigms in order to determine the critical differences between them so as to understand this difference (facilitation versus interference).

Experiment 1

One explanation for the different outcomes in Stroop and lexical decision paradigms is that there is some unidentified but inherent difference between the related word pairs typically used in lexical decision (e.g., DOCTOR-NURSE) and the colour-word pairs typically used in the Stroop paradigm. However, Stroop-like effects have been observed with a variety of semantic categories, such as animal names and numbers (e.g., Schmidt & Cheesman, 2012) and category associates have been shown to produce the same facilitative effect in lexical decision as other types of associates (e.g., Chiarello & Richards, 1992). Further, colour pairs have actually been used as stimuli in lexical decision experiments (e.g., RED-GREEN in Borowsky & Besner, 1991; BLACK-WHITE and GOLD-SILVER in Borowsky & Besner, 1993), though these few items were not analysed separately. Thus, it is our expectation that the incongruent color words and incongruent colour associates typically used in the Stroop paradigm will *facilitate* lexical decisions. In contrast, note that in an inhibition-based model of semantics semantic competition between incongruent distracters and colour targets will lead to less activation being passed on to the response stage. Thus, an inhibition account can only produce an *interference* effect.

Due to the difficulty of generating enough unique colour word pairs to make for a powerful experiment, we opted to use incongruent colour associate primes and colour word targets (e.g., SKY-RED) for Experiment 1. This should not be regarded as a limitation. Like incongruent colour words, incongruent colour associates produce interference relative to a neutral control and this is even true of colour associates that are related to colours that are not potential responses (Risko et al., 2006). Furthermore, colour associates seem to primarily affect the semantic stage of processing (which we are most interested in for the current work), whereas colour words additionally affect the response stage (Schmidt & Cheesman, 2005). Using associates also serves to increase the number of observations per cell. Note that we do, however, use colour word pairs in Experiment 3, where we see the same pattern of results as observed in Experiment 1.

Method

Participants. Thirty-seven undergraduates from the University of Saskatchewan completed Experiment 1 in exchange for course credit.

Apparatus. Stimuli were presented on a standard computer monitor and responses were made on a QWERTY keyboard. Stimulus presentation and response timing were controlled by E-Prime (Psychology Software Tools, 2002).

Materials and design. In the practice block, there were 200 prime-target pairs consisting of 75 semantically-related pairs (e.g., BITTER-SWEET), 25 re-paired semantically-unrelated pairs (e.g., NEST-PLUTO), and 100 nonword trials (e.g., UNDER-KEEK). The relatedness proportion for word trials was therefore 75% in the practice block (intended to promote attentiveness to associations between primes and targets). All participants received the same practice pairs.

Following the practice block, there were 80 test trials, which included 10 incongruent colour associate primed colour words (e.g., BANANA-GREEN) and 10 neutrally primed colour words (e.g., KNOT-PINK). In addition, there were 10 filler semantically-related pairs and 10 filler semantically-unrelated pairs (such that the *word* trials were not all colour words), and 40 nonword trials. The "relatedness" proportion was therefore 50% in the experimental trial block.

Two versions of the trial block were counterbalanced across participants. Nonword trials were the same in both versions. The ten colour words that were primed with an incongruent associate in one version were primed with a neutral word in the other version, and vice versa. Similarly, for the filler items, half of the targets were primed in one version and the other half were primed in the other. Colour associate primes were selected from the University of South Florida free association norms (Nelson, McEvoy, & Schreiber, 1998) based on high association strength with colours. All other stimuli were taken from the word lists in Borowsky and Besner (1993). All items were presented in lowercase, bold, 18 pt Courier New font. The colour word targets, colour associate primes, and neutral primes are presented in the Appendix.

Procedure. Participants sat approximately 60 cm from the screen. Stimuli were presented centrally on a black screen. Each trial began with a white fixation cross. After participants initiated the trial by pressing the spacebar, the prime word was presented for 150 ms, followed by a blank screen for 100 ms, followed by the target word for 2000 ms or until a response was made. Participants pressed the "m" key for words and the "c" key for nonwords. Correct responses were followed by 500 ms of blank screen before the next fixation. Incorrect responses or missed responses were followed by the messages "Incorrect" or "No Response," respectively, in red for 1000 ms before the next fixation. Trials in both the practice and test blocks were randomly ordered for each participant. The two blocks were separated by a break.

Results

Trials in which participants failed to respond were discarded from the analyses (less than 1% of the data). For RTs, only correct responses for the colour word target trials were analysed. Likely due to the very small number of observations per cell, violations of normality (the Shapiro-Wilk test) were observed for both RTs and errors. Non-parametric Wilcoxon signed ranks tests (z) are reported instead. All tests were two-tailed.

RTs. The planned comparison confirmed that participants were *faster* to make lexical decisions to colour words (e.g., RED) preceded by incongruent colour associates (e.g., BANANA; 504 ms) than those preceded by neutral words (e.g., KNOT; 526 ms), $z(36) = 1.969$, $p = .049$.

Errors. The pattern of means was consistent with the RTs, but the percentage of errors to colour words preceded by incongruent colour associates (6.8%) and neutral words (8.6%) did not differ significantly, $z(36) = .741$, $p = .459$.

Discussion

The results of Experiment 1 demonstrate that there is nothing special about the colour stimuli normally used in Stroop experiments. Incongruent colour associates did *not* interfere with lexical decisions to colour words relative to colour-unrelated primes. Instead, as predicted, they *faciltated* performance. The dissociation between the interference effect observed in the Stroop paradigm and the facilitation effect observed in lexical decision therefore has nothing to do with colour or with within-category competition. Thus, an inhibition account of semantic processing seems unlikely, as semantic competition between incongruent primes and colour targets should slow evidence accrual for the correct response relative to the neutral condition.

Experiment 2

Experiment 2 explores another task difference that could be responsible for the dissociation across tasks: the nature of the response. In lexical decision, all that is required of participants is to decide whether the target is a word or nonword. As a result, participants may be making this decision in part by simply measuring whether *anything* is being activated at the lexical or semantic level (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996). With this strategy, it does not matter if multiple concepts are activated, because only a *word* (or a letter string that sounds identical to a word, such as FROOT) can strongly activate semantic representations (by definition, nonwords that neither spell nor sound identical to a word do not have semantic representations). In other words, if both *blue* and *red* are highly activated at the semantic level they need not compete with each other. It does not matter *which* word is the target, only that *any* word is activated. Indeed, the two words will actually facilitate each other given their semantic relation. In the Stroop task, however, participants must decide on the exact identity of the target. Thus, if both *blue* and *red* are highly activated, participants will have to resolve which of the two is the target, a process that will take extra time (interference). The semantic relationship between a prime and a target will actually exacerbate this response conflict; for instance, when presented with BLUE-RED, *blue* will activate *red* and vice versa, making it harder to determine which of the two is the correct response. Consistent with this idea, Klopfer (1996) found that colour words interfered with closely related colours more than less closely related colours (e.g., BLUE interfered more with PURPLE than RED) in the context of a Stroop experiment.

Experiment 2 therefore addressees whether the critical difference between Stroop and lexical decision is the nature of the response that is required in the two tasks. To test this, Experiment 2 is identical to Experiment 1, except that nonwords were removed and participants read aloud the target word (i.e., an identification task) rather than making a lexical decision. It is well established that associative priming is observed when reading aloud (e.g., DOCTOR facilitates NURSE; Besner & Smith, 1992; Lupker, 1984; Seidenberg, Waters, Sanders, & Langer, 1984). Although this sort of associative priming has not been attempted with colour words, it seems likely that incongruent colour associates will serve to prime reading aloud just like regular associates. If facilitation for incongruent colour associates is observed, then neither the type of stimuli nor the nature of the response is the critical difference between Stroop and lexical decision. However, Experiment 2 is quite similar to a standard word-word Stroop experiment, so the possibility that colour associates might interfere with incongruent colours cannot be discounted. Note that, like the previous experiment, if semantic concepts inhibit each other, then evidence for the correct response will be slowed for incongruent relative to neutral primes. In other words, interference is the only possible result in an inhibition-based model of semantics. Facilitation between related concepts, however, could produce facilitation.

Method.

Participants. Forty-six undergraduates from the University of Waterloo completed Experiment 2 in exchange for course credit.

Apparatus. The apparatus for Experiment 2 was identical in all respects to Experiment 1.

Materials and design. The materials and design of Experiment 2 were identical in all respects to Experiment 1 with the exception that there were no nonword trials in Experiment 2.

Procedure. The procedure for Experiment 2 was identical in all respects to Experiment 1 with the following exceptions. Responses were made verbally by participants into a microphone. Following each response, the target word was redisplayed in a smaller 10 pt font, which was used by the experimenter (who was sitting next to the participant) to code whether the response made by the participant was correct, incorrect, or a scratch trial (i.e., the participant failed to respond during the 2000 ms presentation or a microphone error). Following this, correct responses were followed by 250 ms of blank screen. Incorrect responses and scratch trials were followed by the messages "Incorrect" and "Too Slow/Mic Error," respectively, in red for 1000 ms.

Results

Microphone errors and trials in which participants failed to respond were deleted from the analyses (approximately 5% of the data). For RTs, only correct responses for the colour word target trials were analysed. As with the previous experiment, all tests were two tailed. No violations of normality were found in this experiment.

RTs. A planned comparison revealed that participants were *faster* to identify colour words preceded by incongruent colour associates (e.g., BANANA-GREEN; 536 ms) than those preceded by neutral words (e.g., KNOT-PINK; 549 ms), $t(45) = 2.124$, $SE_{diff} = 6$, $p = .039$.

Errors. There were less the 1% errors in both cells of Experiment 2. Not surprisingly then, there were no significant effects of priming ($t < 1$).

Discussion

The results of Experiment 2 demonstrated that the use of an identification type response did not lead to an interference effect. Incongruent prime stimuli (e.g., BANANA) still facilitated identification of colour words (e.g., GREEN) in a lexical-decision-like design where all words were presented only once in the course of the experiment. Thus, like the previous experiment, these results argue against an inhibition-based account of semantics processing, in which competition between colours should have slowed response activation for incongruent relative to neutral trials. A facilitation-based account, however, can explain this effect as an incongruent prime serves to semantically facilitate the correct colour concept.

Experiment 3

Yet another explanation for the difference between Stroop and lexical decision effects is that there is something special about the use of repeated stimuli. As noted in the introduction, in the typical Stroop task a small set of stimuli are repeated multiple times throughout the experiment (e.g., four colour words are presented in four colours 20 times each). This is unlike the typical lexical decision experiment (and both Experiments 1 and 2), where every word appears only once for each participant. Thus, in the Stroop-type design participants may be learning the finite set of possible stimuli and responses via repeated exposure and creating a "response set" strategy. On this account, interference is a by-product of this strategy. Competition between potential responses may only be possible within this response set. If this claim is true, then Stroop-like interference might be observed in a lexical decision task when a small set stimuli are repeated often.

On the other hand, while the repetition of a small set of stimuli may play an important role in producing interference, an identification response might still be required. It does not really matter if multiple potential concepts are activated during lexical decision, because semantic activation of *any* concept indicates that a word has been presented. Thus, there should be no competition. In identification, however, a *specific* target has to be selected (e.g., *either* blue *or* red). It could be that interference only occurs when there is a small set of targets *and* an identification response is required. Perhaps when all words are novel, the primes will simply never get activated enough to compete. When words are repeated continuously, however, their resting activation is high and they can therefore get through to the response system and compete with the target (especially if the target is related in meaning to the prime, causing the prime word to become even more activated). In addition, participants might be lowering their threshold for selecting one of the response set targets, making it even more likely that the prime will get through to the response system along with the target. The goal of Experiment 3 was therefore to assess whether repeating incongruent primes from a small stimulus set *interfere* with or *facilitate* lexical decisions. As with the previous experiments, an inhibition-based account of semantic processing does not predict facilitation, as the competition between the incongruent prime and colour target will slow identification of the target. In contrast, a facilitation account again predicts facilitative effects.

Method

Participants. Ninety-two undergraduates from the University of Waterloo completed Experiment 3 in exchange for course credit. None had participated in Experiments 1 or 2.

Apparatus. The apparatus for Experiment 3 was identical in all respects to Experiment 1.

Materials and Design. In this experiment, there were four colour prime words (BLUE, GREEN, RED, YELLOW), four unrelated prime words (MOVE, SLIDE, WIN, HIDDEN), four colour target words (BLUE, GREEN, RED, YELLOW), and four nonword targets (BLEEN, GRUE, RELLOW, YED). In each of three blocks, each of the eight primes was presented once with each target in random order, for a total of 192 trials (64 trials/block). Unrelated prime words were matched for length with the colour primes. Nonword targets were rearrangements of the colour names (e.g., BLEEN takes the first letters from BLUE and the last letters from GREEN). This was done such that participants could not identify the colour words based on individual letters (e.g., if BLUE was the only target that started with the letter "b"). All words were presented in lowercase, bold, 18 pt Courier New font. This design creates incongruent prime trials (BLUE-RED), neutral prime trials (MOVE-RED), and congruent prime trials (RED-RED).

Procedure. The procedure for Experiment 3 was identical to Experiment 1 with the following exceptions. Participants pressed the "j" key for words and the "f" key for nonwords. The prime word was presented for 200 ms (rather than 150 ms), followed by a blank screen for 50 ms (rather than 100 ms).

Results

Trials in which participants failed to respond were not included in analyses (less than 1% of the data) and only correct responses were used in the RT analyses. For each participant in each cell of the design, RTs greater than 2.5 standard deviations from the mean were excluded (less than 3% of the data; note that a similar procedure was not used in the previous experiments because there were so few observations per cell). Statistical tests were again two-tailed. No violations of normality were found in this experiment.

RTs. Planned comparisons revealed that participants were faster to identify colour words preceded by congruent colour words (573 ms) than those preceded by incongruent colour words

(599 ms), $t(91) = 4.533$, $SE_{diff} = 6$, $p < .001$, and those preceded by neutral words (607 ms), $t(91) = 4.837$, $SE_{diff} = 6$, $p < .001$. More critically, participants were *faster* in the incongruent condition relative to the neutral condition, $t(91) = 2.318$, $SE_{diff} = 3$, $p = .023$.

Errors. Consistent with the RTs, planned comparisons revealed that participants made significantly fewer errors in the congruent condition (3.2%) than in the incongruent condition (4.9%), $t(91) = 2.313$, $SE_{diff} = 0.8$, $p = .023$, and marginally fewer errors than the neutral condition (4.4%), $t(91) = 1.881$, $SE_{diff} = 0.6$, $p = .063$. There was no difference in errors between the incongruent and neutral conditions, $t(91) = 1.011$, $SE_{diff} = 0.5$, $p = .315$.

Discussion

The results of Experiment 3 demonstrate that repetition of a small set of stimuli is not sufficient to produce interference. Incongruent primes still *facilitate* performance in lexical decision relative to neutral primes even when the task design is identical to a word-word Stroop task save for the type of response participants have to make. Yet again, an inhibition-based account of semantic processing cannot explain this finding. Competition between incongruent stimuli could only serve to slow responding. A facilitation account, however, can explain such priming.

Experiment 4

So far, all three of our experiments have observed *facilitative* effects of incongruent stimuli on responding. We propose that interference only occurs when there is a small, finite set of target stimuli *and* an identification response is required. Experiment 4 was run to meet those conditions. Although very similar word-word tasks have produced interference in the context of identification responses (Glaser & Glaser, 1982, 1989), we wanted to ensure that there was nothing peculiar about our particular methodology that was producing facilitation. An inhibition account of semantic processing will, of course, again predict interference effects. A facilitation account also predicts interference effects. The semantic facilitation between incongruent primes and target colours will lead to there being two highly activated responses at the response stage, thus resulting in increased response competition.

Method

Participants. Twenty undergraduates from Ghent University completed Experiment 4 in exchange for course credit.

Apparatus. The apparatus for Experiment 4 was identical in all respects to Experiment 1, except that an AZERTY keyboard was used.

Materials and Design. The materials and design of Experiment 4 were identical in all respects to Experiment 3 with the following exceptions. There were no nonword trials. Stimulus target words were in Dutch (BLAUW [blue], GROEN [green], ROOD [red], GEEL [yellow]), and four new neutral Dutch words were used (NIEUW [new], MAKEN [to make], LANG [long], ZIJN [to be]).

Procedure. The procedure for Experiment 4 was identical in all respects to Experiment 1 with the following exceptions. Responses were made by pressing the “D,” “F,” “J,” and “K” keys, respectively, to blue, green, red, and yellow. The prime and following blank screen duration were the same as Experiment 3.

Results

Trials in which participants failed to respond were not included in analyses (less than 1% of the data) and only correct responses were used in the response latency analyses. Statistical tests were again two-tailed. No violations of normality were found in this experiment.

RTs. Planned comparisons revealed that participants were faster to identify colour words preceded by congruent colour words (663 ms) than those preceded by incongruent colour words (779 ms), $t(19) = 6.845$, $SE_{diff} = 17$, $p < .001$, and those preceded by neutral words (712 ms), $t(19) = 3.993$, $SE_{diff} = 12$, $p < .001$. More critically, participants were *slower* in the incongruent condition relative to the neutral condition, $t(19) = 6.457$, $SE_{diff} = 10$, $p < .001$.

Errors. Planned comparisons revealed that participants made marginally fewer errors in the congruent condition (8.0%) than in the incongruent condition (10.9%), $t(19) = 2.015$, $SE_{diff} = 1.4$, $p = .058$. There was no difference between the congruent and neutral condition (7.6%), $t(19) = .316$, $SE_{diff} = 1.4$, $p = .756$. Critically, participants made significantly *more* errors in the incongruent relative to neutral condition, $t(19) = 2.428$, $SE_{diff} = 1.4$, $p = .025$, consistent with the RTs.

Discussion

The results of Experiment 4 demonstrate incongruent colour words interfere with colour identification in a word-word Stroop task. This experiment helps to relieve concerns that there may have been something unusual about our particular procedure that produced the facilitation effects reported in the first three experiments. Instead, the results lend further credence to our suggestion that interference only occurs when there is a small set of repeated stimuli *and* the task requires target identification. If the task is lexical decision (Experiments 1 and 3) or the set size is large (Experiments 1 and 2), then facilitation occurs. This constellation of results is only interpretable by a facilitation-based account of semantic processing. An inhibition account of semantic level processing predicts interference.

Experiment 5

Experiment 4 demonstrated that an interference effect is observed in identification when a small stimulus response set is used. An interesting question that Experiment 4 did not answer, however, is whether it is the size of the target stimulus and (corresponding) response set that is most crucial or whether the set size of the distracting stimulus set is most important. To answer this question, Experiment 5 uses a small set of repeating target stimuli and a large set of distracting stimuli. On the one hand, one might argue based on a semantic facilitation account that distracters from a large stimulus set may not be primed enough to interfere, but will cause semantic facilitation. Thus, incongruent stimuli might nevertheless produce a facilitation effect relative to controls despite the small response set. We think it more likely, however, that response interference is the result of a small response set. That is, incongruent stimuli will semantically facilitate both the target and its (highly-primed) competitors, leading to greater conflict at the response stage of processing. If so, then interference will be observed for incongruent distracters.

Method

Participants. Twenty-two undergraduates from Ghent University completed Experiment 5 in exchange for €4.

Apparatus. The apparatus for Experiment 5 was identical in all respects to Experiment 4.

Materials and Design. In this experiment, there were four Dutch colour word targets (GROEN [green], BLAUW [blue], BRUIN [brown], PAARS [purple]). Four neutral primes were used in the practice trials (snel [fast], kijken [look], cadeau [gift], schrijver [writer]). Each neutral prime was randomly presented twice with each colour word target, for a total of 32 practice trials. Following practice, the same four colour word targets were presented with incongruent colour word primes or neutral primes. There were a total of 28 incongruent primes and 28 word frequency and letter-length matched neutral primes (see Appendix for the stimuli). Seven of each prime type were assigned to each colour. There were four blocks of trials. In each block, two colour word targets were presented four times with an incongruent prime and three times with a neutral prime, and the other two colour word targets were presented three times with incongruent and four times with neutral. This is because the target was presented *either* with the incongruent prime or the word frequency/letter length matched neutral prime. In Blocks 1 and 4, the same primes were used. In Blocks 2 and 3, the remaining primes were used. Blocks were randomized and consisted of 28 trials each for a total of 112. All words were presented in lowercase, bold, 18 pt Courier New font.

Procedure. The procedure for Experiment 5 was identical in all respects to Experiment 4 with the following exceptions. Responses were made by pressing the "D," "F," "J," and "K" keys, respectively, to green, blue, brown, and purple. The prime and following blank screen duration were the same as in Experiment 4.

Results

Trials in which participants failed to respond were not included in analyses (less than 1% of the data) and only correct responses were used in the RT analyses. Statistical tests were again two-tailed. No violations of normality were found in this experiment.

RTs. A planned comparison revealed that participants were *slower* in the incongruent condition (679 ms) relative to the neutral condition (650 ms), $t(20) = 3.992$, $SE_{diff} = 7$, $p < .001$.

Errors. Although consistent in direction with the RTs, there was no significant difference between incongruent (6.2%) and neutral trials (5.7), $t(20) = .731$, $SE_{diff} = .7$, $p = .473$.

Discussion

Similar to Experiment 4, Experiment 5 revealed a significant impairment of performance on incongruent relative to neutral trials. That is, participants were significantly slower to identify an incongruently-primed colour word than a neutrally-primed one. This result shows that even with a large set of distracters a small response set will lead to interference when an identification response is required. This result is explainable either in terms of semantic level facilitation or semantic level inhibition.

General Discussion

In the series of experiments presented here, we set out to try and resolve a conundrum: Why does the word BLACK *slow* identification of blue print in the Stroop task, but *speed* a lexicality judgment of the word BLUE in the lexical decision task? Experiments 1 and 2 demonstrated that there is nothing special about the category of colour, because incongruent colour associates *facilitated* lexical decisions and reading aloud of color words. Of course, we used colour *words* rather than colour per se, but this is not a critical difference given that colour-word Stroop interference effects generalize to the word-word version of the Stroop task (e.g., Experiment 4; Glaser & Glaser, 1982, 1989), along with a host of similar paradigms (e.g., picture-word Stroop, global-local Stroop, etc.). Experiments 2 and 3 demonstrated, respectively, that neither the identification response type nor the use of repeated words can alone explain why interference is observed in the Stroop task, given that both of these manipulations still resulted in response time facilitation for incongruent primes relative to neutral primes. Interference only occurred in Experiments 4 and 5, where both a small response set *and* an identification response were used.

The facilitative effects of incongruent associates and colour words observed in the first three experiments are not consistent with a semantic inhibition account. In lexical decision, for instance, a colour word target, an incongruent prime, and an incongruent colour word all promote a *word* response. Therefore, the only difference between an incongruent and neutral prime according to an inhibition-based model is that an incongruent prime will inhibit activation of the target colour, and vice versa. As a result of this semantic competition, lexical decision will be impaired. That is, the colour target and colour distracter pass on evidence to the response stage at a slower rate due to the semantic competition between the two. A neutral word, in contrast, will not lead to such conflict (or certainly not to the same degree). We therefore do not see how an inhibition account of semantic processing can produce a facilitative effect of incongruent relative to neutral stimuli. The same is true for the finding of facilitation in identification with a large set size (Experiment 3). Semantic inhibition should only slow identification of the target, not speed it.

Our results suggest, instead, that the connections between concepts in semantic memory are facilitative in nature, not inhibitory. Concepts activate other related concepts via spreading activation (Collins & Loftus, 1975; Qullian, 1967; Neely, 1977; Neely & Kahan, 2001; McNamara, 2005). In other words, colour words and associates *facilitate* semantic processing of incongruent colours. It might be the case that interference only occurs later at the response selection stage. As shown in Figure 1, this will not lead to conflict in lexical decision, because two colour words, even if incongruent, are both words and both therefore indicate the same *word* response. In identification, however, incongruent words indicate different responses (e.g., a *red* vs. *blue* response), which results in competition.

(Figure 1 about here)

It is also possible, however, that no interference exists at all. It could alternatively be the case that a response is selected only when it exceeds the activation of all other competitors by a certain degree (Luce's choice rule; Luce, 1959; see also, Ratcliff, 1978). The distracter and target colour words facilitate each other and work towards the same *word* response in lexical decision, thus producing facilitation relative to neutral. In contrast, incongruent stimuli activate two competing responses in Stroop, thus leading to a lengthening of time to decide between the two options. For instance, although RED might facilitate BLUE semantically, the decision between the two takes longer due to the fact that both potential responses become highly active due to earlier semantic facilitation. With a larger set size (e.g., Experiment 2), the distracter (e.g., RED) might not be active enough to affect the decision criterion for the correct (e.g., *blue*) response very much, but might be active enough to facilitate BLUE semantically. Thus, the semantic facilitation outweighs the cost of having two activated potential responses.

There are other potential explanations for effects of set size. For instance, in the tectonic theory of Melara and Algom (2003) Stroop response decisions are based on the evidence for each of the potential responses. Evidence for a given response is divided by evidence for other responses (much like Luce's choice rule), thus meaning that it will take longer to select the correct response the more active the competitors are. Firstly, facilitation between incongruent semantic concepts would lead to more such competition, thus providing a good explanation for a difference between incongruent and neutral stimuli. Secondly, such a decision mechanism might only be useable by the cognitive system when there are a finite set of potential responses to consider. When every single trial involves a new distracter and new target (e.g., Experiments 1 & 2), then the cognitive system may not apply such a decision mechanism as a result of the fact it learns that the response for all of the past trials cannot be the response for the current trial. As a result, decisions in large response set experiments may simply be based on a "horse race" to the finish. In other words, incongruent trials might still provide two strongly activated potential responses (i.e., due to semantic facilitation earlier on), but this will not lead to response competition (i.e., because evidence for the colour response is not being divided by evidence for the word response). More generally, the cognitive mechanisms that lead to response competition (whatever they are) might only engage when a small set of highly primed responses are being repeatedly used.

Our suggestion that all semantic connections are facilitative is certainly not typical, as many models rely on inhibitory connections. For instance, in the interactive activation (IA) framework connections within a given level are *competitive* (McClelland & Rumelhart, 1981), including semantics (e.g., McClelland, 1987). As well, formal models of the Stroop effect typically rely on inhibitory connections (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Zhang, Zhang, & Kornblum, 1999). As a slight variant, some accounts suggest that a top-down inhibitory mechanism dampens activation of concepts that are closely-related to the target (e.g., Dagenbach & Carr, 1994). Although atypical, not only is a solution based on facilitation more efficient computationally (only related concepts need to be connected, whereas in an inhibition-based model *every single semantic concept* needs to be connected to *every other semantic concept*, which would require approximately 200 million connections in a vocabulary of 20,000 words), but it also seems more reasonable (and biologically plausible) to assume that *related* concepts should be connected in a facilitative manner and that *unrelated* concepts should not be connected at all.

Note that it is not being argued that other models of Stroop performance have everything wrong. We still assume that conflict occurs during response selection and a wide array of Stroop models can help to explain this response conflict. Rather, our goal here is merely to suggest a modification to extant theories of Stroop performance. Specifically, we mean to suggest that during semantic processing (which is not even modelled in many accounts) there should be facilitative links between related concepts. Direct associates, such as the various colours, should have facilitative connections. Similarly, indirect associates, such as colour associates, should have facilitative connections to their related colours (which are then connected to the other colours). These connections help to exacerbate later response conflict and can be included in any of the major models of Stroop performance. In other words, we mean to point out that interference effects do not necessarily imply purely inhibitory mechanisms.

On a less theoretical level, the present experiments provide useful information about the task differences that allow for facilitation in some contexts and interference in other contexts. Specifically, we identified response type (e.g., lexical decision vs. identification) and response set size (i.e., large vs. small) as two key factors. Semantic relationships, even if “incongruent,” seem to facilitate performance in all cases when lexical decision is required. This is likely due to the fact that incongruent stimuli do not indicate a conflict response (i.e., because they are also words). In identification, however, conflict is sometimes possible, likely due to the fact that response conflict can occur when the target and distracter suggest different responses. This finding helps resolved the opposite results obtained for semantically-related distracters in lexical decision and Stroop. Set size also seems to be important. Interference only seems to occur when a small set of repeated responses is required. This latter finding helps to resolve the difference in direction between semantic priming and Stroop effects in reading aloud experiments. The final experiment in the present paper further shows that it appears to be the response set size that is truly critical, rather than the distracter set size. Further research investigating such structural differences between various cognitive paradigms is certainly welcome. Our view is that such comparisons can be highly informative for the development of deeper theoretical issues, as we have tried to argue with our contrasting predictions of semantic facilitation versus inhibition accounts.

Conclusion

The present experiments present preliminary evidence for a spreading activation (or semantic overlap in semantic feature space) model of semantics with facilitative connections only. Stroop-like response competition, according to this account, only occurs when multiple competing responses are generated. This situation only arises, according to our analysis, when responses are highly primed via repeated presentation and, in addition, participants are required to identify the exact target stimulus (e.g., rather than just indicate that it is a word). On a more general level, we aimed to highlight some of the important structural differences between Stroop and lexical decision experiments that may be useful to consider when developing theoretical accounts of such effects. The present work may serve to inspire further cross-paradigm research so as to better integrate our often fragmented discipline.

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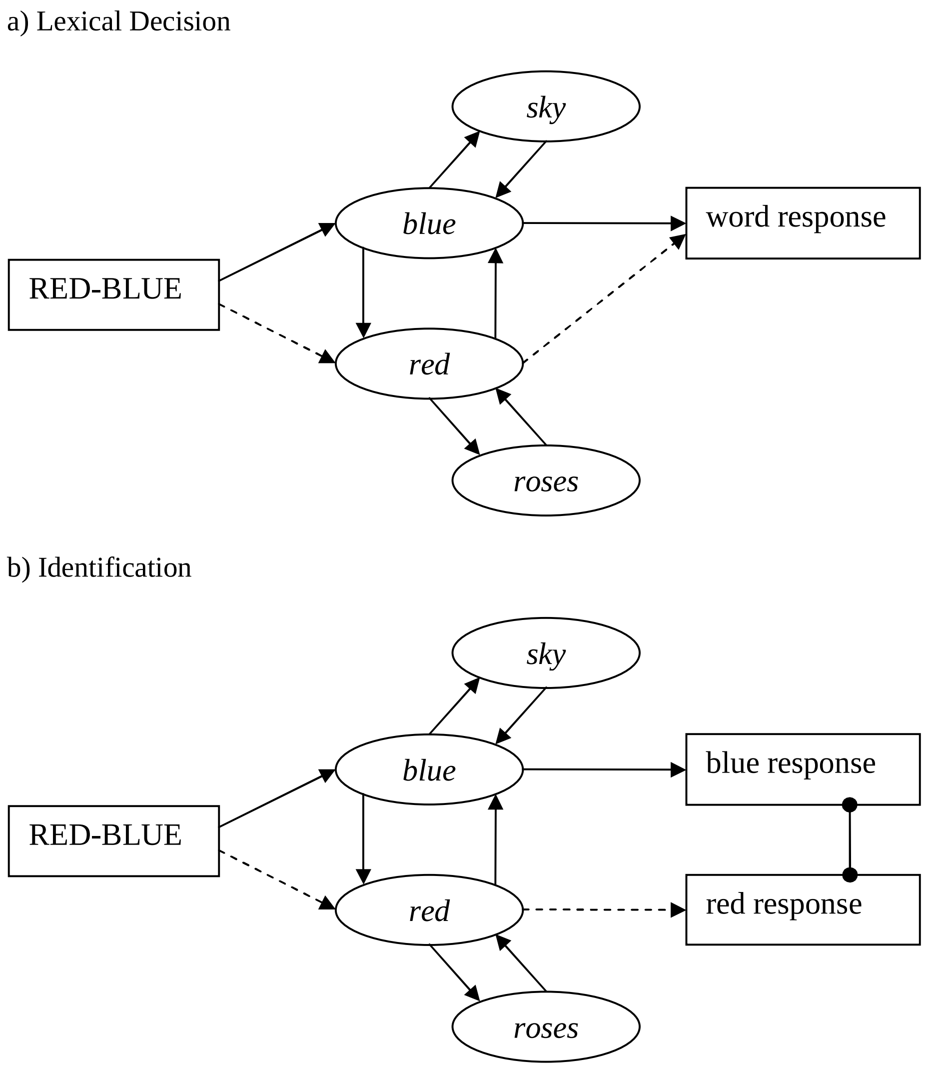

Figure 1. Stimulus processing with facilitative semantic connections only in (a) lexical decision, and (b) identification. Response codes can only compete if identification of the specific target is necessary.

Appendix

Stimuli for Experiments 1 & 2

Colour word targets: *black, brown, gold, green, lime, pearl, purple, ruby, tan, white, ivory, silver, violet, yellow, blue, cinnamon, grey, orange, pink, red*

Colour associate primes: *coal, brunette, jewelry, plants, lemon, necklace, grape, sapphire, sun, pale, tusk, tarnish, roses, banana, sky, spice, matter, juice, panther, beet*

Neutral primes: *wood, camel, thursday, rake, mercury, vision, mars, moccasins, knot, oak*

Stimuli for Experiment 5

Incongruent colour word primes: *cyan, oker, magenta, scharlaken, zwart, zilver, beige, lila, roze, sepia, rood, oranje, mauve, amber, bordeaux, wit, fuchsia, violet, geel, turkoois, grijs, indigo, smaragden, purper, framboos, sienna, kaki, vermiljoen* (English: cyan, ocher, magenta, scarlet, black, silver, beige, lilac, pink, sepia, red, orange, mauve, amber, burgundy, white, fuchsia, violet, yellow, turquoise, gray, indigo, emerald, purple, raspberry, sienna, khaki, vermilion)

Neutral word primes: *vleug, rune, uitvoer, afwikkelen, adres, schild, adieu, piep, merk, sprot, roep, zinken, rabat, genot, stoornis, lid, zijspan, janken, wijk, inlijven, naald, saluut, toepassen, tutten, doctrine, modaal, amok, affiniteit* (English: nap, rune, export, unwinding, address, shield, farewell, beep, brand, sprat, call, sinking, rebate, enjoyment, disorder, member, sidecar, whining, district, recruiting, needle, salute, apply, dressed up, doctrine, modal, amok, affinity)