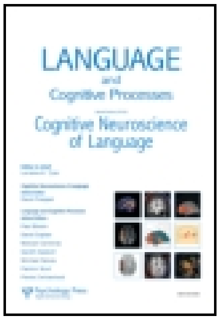

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Relative speed of processing affects interference in Stroop and picture-word interference paradigms: evidence from the distractor frequency effect

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Relative speed of processing affects interference in Stroop and picture–word interference paradigms: evidence from the distractor frequency effect

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The Stroop and picture–word interference (PWI) paradigms play a pivotal role in theorising about cognitive processes in general, and language production in particular. A common assumption is that the same mechanisms underlie performance in these two paradigms. Despite this assumption there exist empirical discrepancies. Here we focused on providing a unifying account for the contrasting effects of distractor word frequency in the two paradigms. In four experiments, we addressed whether the contrast is due to inherent design differences between the two paradigms (i.e., grammatical class, stimulus display and relative speed of processing). The results showed that the distractor frequency effect is contingent upon the overall naming latencies in the paradigm, suggesting that the speed of processing target colours and pictures relative to distractor words affects performance in the two tasks. The implications of these results for various models of language production are discussed.

Keywords: the picture–word interference paradigm; Stroop; distractor frequency effect

The Stroop and picture–word interference (PWI) paradigms play an important role in theories of word selection and attentional control across various branches of cognitive psychology (e.g., Glaser & Glaser, 1989; Lupker, 1979; Roelofs, 2003). A proper understanding of the processes that underlie these paradigms is therefore crucial for progress in these fields. A common assumption is that effects that arise in these two paradigms can be explained in terms of similar mechanisms (e.g., Cohen, Dunbar, & McClelland, 1990; Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Roelofs, 2003). However, although the majority of empirical data obtained from the two tasks is indeed comparable, there exists an empirical discrepancy in the way the frequency of a distractor word affects colour and picture-naming times. Specifically, whereas naming latencies are faster in the context of high-frequency distractor words than low-frequency distractor words in the PWI task (e.g., Miozzo & Caramazza, 2003), this effect is less clear for the Stroop paradigm (e.g., Monsell, Taylor, & Murphy, 2001). If this empirical discrepancy between the two tasks were confirmed, it could imply that different mechanisms underlie performance in the two tasks, thereby prompting a re-evaluation of extant models in a number of fields. In this study, we first attempted to confirm the contrasting effects of distractor frequency between the Stroop and PWI tasks. We then discuss the competing predictions of three theoretical accounts of the distractor frequency effect (i.e., grammatical class, stimulus display and relative speed of processing) across the Stroop and PWI paradigms. Finally, we propose a unifying account to explain the distractor frequency effect in both paradigms.

In general, the Stroop and PWI paradigms appear similar, both descriptively and behaviourally. In the standard Stroop paradigm, words are written in different colour inks. Participants name the ink colour and ignore the written word (e.g., Stroop, 1935). Likewise, in the PWI paradigm, participants name pictures and ignore embedded distractor words (e.g., Rosinski, Golinkoff, & Kukish, 1975). For both Stroop and PWI paradigms, semantic similarity between the target and distractor produces interference. For example, in the Stroop paradigm, colour-naming times are slower when colour distractor words differ from the target colour (e.g., the word red written in green ink; incongruent condition) than when distractor words are the same as the target colour (e.g., the word red written in red ink; the congruent condition). This difference in naming latencies is referred to as the standard Stroop effect. In addition, colour-naming latencies are slower in the incongruent condition than in a neutral condition (e.g., a string of X's), which is referred to as Stroop interference. Similarly in the PWI paradigm, naming times are slower for pictures (e.g., dog) paired with semantically related words (e.g., CAT) vs. identity words (e.g., DOG; usually not analysed in PWI contexts), or unrelated words (e.g., TABLE; referred to as a semantic interference effect).

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Although effects observed in the Stroop and PWI paradigms behave similarly, previous studies show that manipulating the frequency of an unrelated distractor word has a different impact on target-naming latencies between paradigms. Specifically, in the PWI task, Miozzo and Caramazza (2003) observed that picture naming (e.g., bottle) is slower in the context of low-frequency, unrelated, word distractors (e.g., HARP) than high-frequency distractors (e.g., GIRL; PWI, Experiments 1–7; see also Dhooge & Hartsuiker, 2010, 2011). By contrast, in the Stroop task, the distractor frequency effect is less reliably observed. Klein (1964) and Fox, Shor, and Steinman (1971) found the reverse distractor frequency effect – colour naming was slower in the context of non-colour high-frequency distractors than non-colour low-frequency distractors. In contrast, Burt (1994, 2002) found the distractor frequency effect in two studies. However, these studies were criticised on methodological grounds (e.g., see Miozzo & Caramazza, 2003, Monsell et al., 2001, and Kahan & Hely, 2008 for details). Elsewhere, a combined analysis of three experiments demonstrated that colour naming (e.g., red) was unaffected by the frequency of distractor words (Monsell et al., 2001). Thus, whereas distractor frequency affects naming latencies in the PWI task, it is at present unclear to what extent the same pattern of results is found in the Stroop task.

Current explanations of the distractor frequency effect in the language production literature predict that the effect should occur in both the PWI and Stroop paradigms. One recently proposed account of performance in the PWI task called WEAVER++ (Roelofs, 2003) accounts for the distractor frequency effect in terms of processes arising at an input level. Specifically, the distractor frequency effect is assumed to reflect the impact of attentional control over perceptual input which amplifies the target perceptual input and reduces the word distractor input. This modulation of perceptual input for word distractors is sensitive to word frequency (Roelofs, 2003, 2005). Perceptual blocking occurs more quickly for high-frequency than low-frequency words, resulting in faster target-naming latencies in the presence of high- vs. low-frequency words. A consequence of these assumptions is that this model predicts a distractor frequency effect in both PWI and Stroop paradigms. That is, perceptual blocking of the distractor words is assumed to take place in both PWI and Stroop paradigms, and hence, comparable effects of distractor word frequency are expected in the two tasks.

An alternative account of performance in the PWI task is the Response Exclusion Hypothesis (Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). This account explains the effect of distractor word frequency in terms of output-level processes. Specifically, word distractors have privileged access to a single-channel response output buffer in a way that pictures do not. The consequence of this assumption is that distractors appear in the output buffer *earlier* than the target picture/colour name responses. Consequently, the buffer needs to be cleared (unblocked) for the target production to take place. Low-frequency words arrive in the buffer later than high-frequency words and, hence, are excluded from the buffer later, leading to slower picture-naming times in the context of low- vs. high-frequency distractor words. Without any further assumptions, this explanation of the distractor frequency effect in the PWI task also predicts that distractor frequency should also affect colour-naming latencies in the Stroop task [for further discussion on the Response Exclusion Hypothesis and the competition hypothesis (e.g., WEAVER ++), see Abdel Rahman & Aristei, 2010; Hantsch & Mädebach, 2011; Janssen, 2013; Mädebach, Oppermann, Hantsch, Curda, & Jescheniak, 2011; Mulatti & Coltheart, 2012; Navarrete & Mahon, 2012; Piai, Roelofs, & Schriefers, 2011; Roelofs, Piai, & Schriefers, 2012].

To summarise, whereas the distractor frequency effect has been reliably observed in the PWI task (Dhooge & Hartsuiker, 2010, 2011; Miozzo & Caramazza, 2003), the reliability of this effect in the Stroop task is questionable. This empirical discrepancy undermines the common assumption that there are similar underlying mechanisms in the two tasks and is problematic for the two leading explanations of performance in the PWI and Stroop tasks (i.e., WEAVER++ and the Response Exclusion Hypothesis). However, it is important to point out that the comparison of the distractor frequency effects between the Stroop and PWI paradigms currently relies on different materials and experimental designs. For example, different studies rely on different participants and different sets of distractor words, raising the possibility that methodological differences could account for the discrepant results. Thus, before drawing further any conclusions we need to rule out that methodological differences account for the contrasting effects of distractor frequency that exist in the literature.

The goal of this paper was twofold. First, we tested the distractor frequency effect in both Stroop and PWI, while controlling for previous methodological differences. Specifically, in Experiment 1, we compared the distractor frequency effects in the Stroop and PWI paradigms using a within-subject and within-materials design. In subsequent experiments we tested for several factors that may account for the observed contrasting effects of the distractor frequency effect. Second, we attempted to provide a unifying account of the distractor frequency effect across the Stroop and PWI paradigms. Specifically, we show how existing proposals of performance in the Stroop and PWI paradigms can be modified such that they can account for the pattern of results reported here.

Experiment 1

The objective of Experiment 1 was to test whether methodological differences account for the previously observed contrast in the distractor frequency effect between the Stroop and PWI paradigms. In Experiment 1a, the participants took part in both Stroop and PWI paradigms in the context of two types of word distractors: high frequency vs. low frequency (e.g., Stroop: colour: red, distractor word: SCHOOL vs. SPLEEN). Importantly, the same distractors were used for both paradigms.

Based on Miozzo and Caramazza (2003), we expected participants to take longer to name pictures in the presence of low-frequency compared to high-frequency words (the standard distractor frequency effect) in the PWI paradigm. Based on the data from the previous Stroop studies, we expected no distractor frequency effect or a small distractor frequency effect in the Stroop paradigm. Thus, we predicted an interaction between the two paradigms and the distractor frequency effect. In Experiment 1b, we replicated the results of Experiment 1a in the Stroop paradigm with another 24 participants.

Method

Participants

In this and the following experiments, all participants were native English speakers at Rice University and received credit or were paid for their participation. All subjects gave informed consent in accordance with the protocol approved by the Institutional Review Board of Rice University. Twenty-four native English speakers (10 male) took part in Experiment 1a, and a different twenty-four (9 male) in Experiment 1b.

Materials

There were 80 distractor words, 40 high-frequency and 40 low-frequency words, all taken from Miozzo and Caramazza (2003; Experiments 3–4) in both PWI and Stroop paradigms. As Miozzo and Caramazza (2003, p. 232) reported, high- and low-frequency words (all nouns) were matched for word length, concreteness, the number of neighbors, word mean bigram frequency and a measure of grapheme-to-phoneme consistency. For the Stroop paradigm, four colours (red, blue, green and yellow) were randomly assigned to all 80 words, such that each word was seen once in one of the four colours. For the PWI paradigm, we used the same 20 target picture names from Miozzo and Caramazza (2003; Experiments 3–4), selected from the Snodgrass and Vanderwart (1980) set. We paired each picture with two high-frequency and two low-frequency words. The picture–word pairs used in the Experiment 1a are reported in Appendix 1.

Design

For both paradigms, the two conditions (40 high-frequency and 40 low-frequency words) were combined into four blocks. For the Stroop paradigm, each block contained 10 high-frequency and 10 low-frequency words paired with four colours. For the PWI paradigm, each block contained 10 high-frequency and 10 low-frequency words paired with 20 target pictures. Trial presentation within each block was pseudo-randomised such that no colour, picture or word was repeated on consecutive trials. In Experiment 1a, each subject saw all four blocks for both paradigms. The order of the paradigms was balanced among participants and the order of block presentation was counterbalanced across subjects. For the Stroop paradigm, four warm-up trials of words written in red, yellow, blue and green were included at the beginning of each block. The total number of trials was 96. For the PWI paradigm, we used three new pictures (i.e., flower, car, sun) with distractor words as the warm-up trials at the beginning of each block. The total number of trials was 92. The distractor words used as the warm-up trials in both Stroop and PWI paradigms were never used either in the practice or experiment phases.

In Experiment 1b, each subject saw all four blocks only for the Stroop paradigm. The total number of trials was 96.

Procedure

The following procedure was used in all of the Stroop and PWI paradigm experiments reported in this article. The experiment was operated by the software DMDX (Forster & Forster, 2003). All participants were tested individually in a dimly lit testing room and seated at a distance of about 65 cm from the computer screen. In the Stroop paradigm, words were presented in capital letters in Times New Roman 16-point font (10–11 mm) on a colour monitor with a dark background. The participants were instructed to name the colours and ignore the distractor words.

The procedure for the Stroop paradigm was identical to that in Burt (2002)'s Experiment 4. On each trial, the fixation point (i.e., +++) in white was shown in the centre of the computer screen for 500 ms, the dark screen was displayed for 250 ms and the word appeared in red, green, blue or yellow until a vocal response was detected. An interval of 3 seconds then elapsed before the next fixation display. A 12-trial practice phrase using words that were never used in the experiment phrase preceded the experiment phrase.

In the PWI paradigm, words were presented in capital letters in Times New Roman 12-point font (8–10 mm). All pictures were scaled into 300 × 300 pixels. For each picture, the distractor word was always presented in a random location [i.e., the average distance between the centre of a distractor word and picture was 53 pixels (the standard deviation: 24), see Figure 1]. The participants were instructed to name the pictures and ignore the distractor words.

Figure 1. A sample stimulus for the PWI paradigm.

There were three phases: a learning phase, practice phrase and experimental phase. In the learning phase, the participants familiarised themselves with the pictures and their names. Pictures were shown with their names underneath, but without superimposed distractor words and they would appear until participants named it aloud. In the practice phase, the participants were presented with all the pictures with distractor words that did not appear in any of the experimental trials to familiarise the procedure of the experiment.

A trial was structured as follows: a fixation point (+) was displayed in the centre of the screen for 700 ms, and then was replaced by the stimulus. Stimuli disappeared once participants responded. If the voice key was not triggered, the picture was shown for 3 seconds. The subjects were asked to respond as quickly and as accurately as possible and an experimenter coded errors. Experiment 1a lasted for 20 minutes. Experiment 1b lasted for 10 minutes.

Results

Experiment 1a

Naming latencies were discarded from the analyses whenever any of the following occurred: (1) a picture was named incorrectly; (2) subjects made a noise (e.g., cough); (3) the voice key failed to trigger; and (4) response times (RT) deviated from a participant's mean by more than three standard deviations. The first two were coded as participant errors. For the Stroop paradigm, 3.4% (including 1.7% participant errors) of the data points were removed. For the PWI paradigm, 4.7% (including 2.2% participant errors) of the data points were removed. Two ANOVAs were computed with participants and items as random variables. Fixed variables were distractor frequency condition (high frequency vs. low frequency) and paradigm type (Stroop vs. PWI). The distractor frequency was a within-subject and between-item variable, and paradigm type was a within-subject and within-item variable. For the item analysis in all the experiments, distractor words were the unit of analysis (e.g., high- and low-frequency words: $df = 78$). Logistic regression (e.g., Agresti, 2002) was employed for the error analyses in this and following experiments. An overview of the mean RTs and error rates for the two paradigms is presented in Table 1.

In the error analysis, there were no significant effects in either Stroop or PWI paradigms (Stroop: χ^2 (1) = 0.12, $p = 0.73$; PWI: χ^2 (1) = 0.88, $p = 0.35$). In the analysis of naming latencies,[1] colour naming in the Stroop paradigm was significantly faster than picture naming in PWI (F_1 (1, 23) = 16.98, $p < 0.001$, MSE = 5935.15; F_2 (1, 78) = 153.67, $p < 0.001$, MSE = 1015.13). There was a main effect of the distractor frequency (F_1 (1, 23) = 11.91, $p = 0.002$, MSE = 377.49; F_2 (1, 78) = 8.27, $p = 0.005$, MSE = 1137.42) indicating slower naming latencies for low-frequency words than high-frequency words. There was a significant interaction between frequency condition and paradigm, suggesting that the size of the distractor frequency effect was significantly larger in the PWI compared to Stroop paradigm (F_1 (1, 23) = 5.07, $p = 0.03$, MSE = 618.84; F_2 (1, 78) = 5.44, $p = 0.02$, MSE = 1015.13). In the PWI paradigm, a planned *t*-test (two-tailed) showed that naming latencies were 28 ms slower for low- than high-frequency distractors (t_1 (23) = 3.91, $p < 0.001$; t_2 (78) = 3.28, $p = 0.002$). However, in the Stroop paradigm, there was no significant difference between high- and low-frequency conditions (*t*'s < 1).

Table 1. Naming latencies (ms) for colour naming (Stroop) and picture naming (picture–word interference paradigm, PWI) and their error rates (in parentheses) when paired with high- and low-frequency words in Experiments 1 and 2.

		LF words	HF words	Difference (ms)[a]
Experiment 1a	Stroop	629 (0.03)	626 (0.04)	3
	PWI	704 (0.05)	676 (0.05)	28*
Experiment 1b	Stroop	639 (0.04)	633 (0.04)	6
Experiment 2	PWI	592 (0.04)	592 (0.05)	0

LF, low frequency; HF, high frequency.
[a]Difference between LF and HF word distractors.
*$p < 0.05$.

Previous task-switching studies show that task 1 can have a long-lasting effect on task 2. For example, Allport, Styles, and Hsieh (1994) reported that a strong reverse Stroop effect was observed in a word-naming task if the words were seen in a previous Stroop task. Hence, we tested whether there was an interaction between task order (first vs. second) and frequency (high vs. low) in the two paradigms. In both paradigms, there was no significant interaction between order and frequency (Stroop: F_1 (1, 22) = 1.12, $p = 0.30$, MSE = 286.30; F_2 (1, 78) = 1.55, $p = 0.22$, MSE = 759.84; PWI: *F*'s < 1).

Experiment 1b (a replication of the null effect in the Stroop paradigm)

Latency data were preprocessed in the same way as in Experiment 1a; 4.1% (including 2.4% errors) of the data points were removed. An overview of the mean RTs and error rates for the two paradigms is presented in Table 1. Logistic regression was employed for the error analysis. There was no significant frequency effect (χ^2 (1) = 0.80,

p = 0.37). In the analysis of naming latencies, a paired-samples t-test was computed comparing colour naming with high- and low-frequency distractor words in the Stroop paradigm for the subject analysis. For the item analysis, an unpaired-samples t-test was computed. There was no difference between high- and low-frequency conditions (t_1 (23) = 1.52, p = 0.14; t_2 (78) = 1.24, p = 0.22).

In order to see whether the distractor frequency effect in the Stroop paradigm in Experiment 1b was different from that in the PWI of Experiment 1a, we computed an ANOVA with participants and items as random variables. In the analysis of naming latencies, we found again that colour naming in the Stroop paradigm was significantly faster than picture naming in the PWI paradigm (F_1 (1, 46) = 5.19, p = 0.03, MSE = 12,970.99; F_2 (1, 78) = 115.60, $p < 0.001$, MSE = 1043.77), and overall naming latencies were significantly slower for low- than high-frequency words (F_1 (1, 46) = 13.76, p = 0.001, MSE = 460.49; F_2 (1, 78) = 12.25, p = 0.001, MSE = 943.53). However the significant distractor frequency effect was driven solely by the PWI paradigm, as demonstrated by the significant interaction between frequency condition and paradigm, indicating that the size of the distractor frequency effect was again smaller (and non-significant) in the Stroop compared to the PWI paradigm (F_1 (1, 46) = 5.03, p = 0.03, MSE = 460.49; F_2 (1, 78) = 3.91, p = 0.05, MSE = 1043.77).

Discussion

The results of Experiment 1 can be summarised as follows. Target-naming latencies were slower in the context of low-frequency distractors compared to high-frequency distractors when the targets were pictures (the PWI paradigm), but were unaffected by the frequency of the distractors when they were colours (the Stroop paradigm). This pattern of results is consistent with the results in previous PWI studies (Dhooge & Hartsuiker, 2010, 2011; Miozzo & Caramazza, 2003), and with previous Stroop studies (e.g., Monsell et al., 2001). These results show that previous contrasting effects of distractor frequency outlined in the Introduction section are unlikely to be attributable to the different stimuli or participants involved in these studies. Even when the same participants performed both paradigms with one set of high- and low-frequency words, the contrasting results remained.

The presence of the distractor frequency effect in the PWI paradigm and the absence of the effect in the Stroop paradigm are inconsistent with the predictions of the Response Exclusion Hypothesis (Mahon et al., 2007) and WEAVER++ (Roelofs, 2003) discussed in the Introduction. This implies that both the Response Exclusion Hypothesis and WEAVER++ need to postulate different mechanisms for the Stroop and PWI tasks. However, before accepting this conclusion, we consider whether there are any inherent design differences between the two paradigms that might account for the results.

What may cause these contrasting effects of distractor frequency between the PWI and Stroop task? Here we consider three possible differences that are typical of experimental designs using the PWI and Stroop tasks that could explain the contrasting results. First, in the PWI paradigm, all distractor words and pictures were from the same grammatical class (i.e., nouns) whereas in the Stroop paradigm, the grammatical class of the target was different from the grammatical class of the distractor words (targets were always colour adjectives; distractor words were nouns). Previous PWI studies have found that picture-naming latencies are impaired only when the distractor word is of the same grammatical class as the target picture name (e.g., Pechmann, Garrett, & Zerbst, 2004; Pechmann & Zerbst, 2002; Vigliocco, Vinson, & Siri, 2005; but see Janssen, Melinger, Mahon, Finkbeiner, & Caramazza, 2010). Accordingly, the contrasting pattern of distractor frequency effects between the PWI and Stroop tasks observed here may reflect the differences in the grammatical class relationship between target and distractor.

A second possible explanation for the contrasting results observed in Experiment 1 is in terms of the different stimulus displays. Specifically, the stimulus displays of the PWI and Stroop tasks differ in terms of the separability of the two stimuli in the display. Whereas the picture and word stimuli in the PWI task are physically separate stimuli, the colour and word stimuli are integrated into a single stimulus. It is possible that such differences in the stimulus display impact the contrasting effects of distractor frequency between the two paradigms.

Another possible account of Experiment 1 is that the Stroop task involves non-standard target retrieval. Due to a small response set accompanied by high repetition of target colours, participants may retrieve the targets without going through the full lexicalisation procedure, resulting in no distractor frequency effect. However, this explanation does not readily explain why the standard Stroop effect is observed under conditions of high repetition of three or four targets. Although the standard Stroop effect argues against a non-standard target retrieval account, we also test this possibility in Experiment 3.

A final explanation of the contrasting effects of distractor frequency observed in Experiment 1 is in terms of variables that impact the relative speed of processing targets and distractor words in the two tasks. The differences in response set size and repetition between the Stroop (4 colours with 20 repetitions) and PWI tasks (20 pictures with 4 repetitions) could lead to faster retrieval times for colour names than for picture names in the two tasks. If we assume that the speed of distractor word processing were equal in the two tasks (i.e., the same words were presented under comparable conditions), then we explain the observed contrasting effects of distractor frequency between the two tasks in terms of differences in the relative time of target and distractor word processing. Specifically, the absence of the distractor frequency effect in the Stroop task may arise because the distractor word is processed 'too late' to affect colour naming, and the presence of the effect in the PWI task may arise because the distractor word is processed 'on time' to affect picture naming. Importantly, note that this explanation of the pattern of results in terms of the relative speed of processing is compatible with both input and output accounts of the distractor frequency effect – 'too late' means that target processing has passed beyond the stage where it is affected by perceptual input (WEAVER++), or by blocking of an output buffer (i.e., response exclusion).

If the contrasting results in Experiment 1 reflect the influence of the relative speed of processing, then we should observe that the presence of the distractor frequency effect in previous studies is correlated with overall naming times in these studies. This indeed seems to be the case. Specifically, picture-naming response times were around 700 ms in our own experiment and the PWI studies of Miozzo and Caramazza (2003), and the distractor frequency effect was reliably observed. By contrast, average colour-naming latencies were much faster in the Stroop task (i.e., 628 ms in our experiment; 550 ms in Monsell et al., 2001), and no reliable effect was observed. Thus, previous studies are consistent with the hypothesis that factors that impact the relative speed of processing drive the contrasting effects of distractor frequency in the two tasks.

To summarise, the contrasting effects of distractor word frequency in PWI and Stroop paradigms observed in Experiment 1 might be explained by differences in terms of the grammatical class of targets and distractor words, by differences in the stimulus display, or by variables that impact the relative speed of processing between the targets and distractor words. In Experiments 2 and 3, we distinguished between these three possible explanations. In Experiment 2, participants named pictures in the context of low- and high-frequency distractor words where four pictures repeated 20 times. If grammatical class explains the presence of a distractor frequency effect in Experiment 1, we expected an effect in Experiment 2, since both targets and distractors are from the same grammatical class. Similarly, if the presence of the distractor frequency effect in the PWI is a result of the physical separation of the picture and word stimuli, we also expected a distractor frequency effect in Experiment 2, since picture and word stimuli were separated. Finally, if the small set size and high repetition of the target pictures increase the speed with which the pictures are processed, we expected a weaker or no distractor frequency effect in Experiment 2. In Experiment 3, we further compared the relative speed and grammatical class accounts discussed above.

Experiment 2 – PWI paradigm with four pictures

Method

Participants

Twenty native English speakers (9 male) took part in Experiment 2.

Materials and procedure

We used the same materials and design of the Stroop paradigm in Experiment 1 (only high- and low-frequency conditions). The only difference was that we used four pictures instead of four colours. The four pictures were CAR, PIG, TREE and HAT. The picture names in Experiment 2 were matched on frequency, word length, imageability (ratings taken from the MRC psycholinguistic database, Coltheart, 1981) and the number of syllables to colours in Experiment 1 (see Table 2). The four pictures were randomly assigned to all 80 high- and low-frequency words, such that each word was seen in one of the four pictures. The procedure was the same as for the PWI paradigm in Experiment 1a. The experiment lasted for 10 minutes.

Results

Latency data were preprocessed in the same way as in Experiment 1; 4.2% (including 2.6% errors) of the data points were removed. An overview of the mean RTs and error rates for this experiment is presented in Table 1. There was no significant frequency effect for the error analysis ($\chi^2(1) = 0.39$, $p = 0.51$). In the analysis of naming latencies, a paired-samples t-test was computed comparing high- and low-frequency words for the subject analysis. For the item analysis, an unpaired-samples *t*-test was computed. There was no difference between high- and low-frequency conditions (*t*'s < 1).

In order to see whether the distractor frequency effect in Experiment 2 was different from the effect in the PWI of Experiment 1a, we computed an ANOVA with participants and items as random variables. In the analysis of naming latencies, we found that picture naming in this experiment was significantly faster than that in Experiment 1a PWI ($F_1\,(1, 42) = 3167.57$, $p < 0.001$, MSE = 11,315.40; $F_2\,(1, 78) = 333.15$, $p < 0.001$, MSE = 1184.74). There was

Table 2. Mean measurements of colour and picture names in Experiment 2.

Variables	Colour	Picture
Frequency	128	99
Imageability rating	590	614
Word length	4.5	3.3
Number of syllables	1.3	1

a significant interaction between frequency condition and experiment, indicating that the size of the distractor frequency effect was again smaller (and non-significant) in this experiment compared to Experiment 1a PWI (F_1 (1, 42) = 10.52, p = 0.002, MSE = 383.57; F_2 (1, 78) = 5.85, p = 0.02, MSE = 745.53).

Discussion

In Experiment 2, participants named pictures in the PWI paradigm using the basic design features of a Stroop task, where four target pictures were repeated 20 times. Under such experimental conditions, overall naming latencies were substantially faster than in the 'normal' PWI task of Experiment 1. Importantly, under these conditions we failed to observe a distractor frequency effect.

These results are inconsistent with the grammatical class and stimuli display accounts. According to the grammatical class account, distractor frequency effects are expected only when the target and distractor are from the same grammatical class. At odds with this expectation, we did not observe a distractor frequency effect in Experiment 2, even though target and distractors shared grammatical class. Similarly, the stimuli display account predicts a distractor frequency effect when the target and distractor are physically separated. However, we did not observe a distractor frequency effect in Experiment 2 using physically separated stimuli.

Finally, the results of Experiment 2 find a ready explanation in terms of the relative speed of processing of target and distractor stimuli hypothesised to drive the distractor frequency effect. According to this hypothesis, reducing the number of targets and increasing the number of target repetitions increases the speed with which a target is retrieved. Compared to Experiment 1, target processing in Experiment 2 sped up to such a degree that the distractor was processed 'too late', and no longer affected target retrieval times. Consistent with a relative speed account, in Experiment 2 no distractor frequency effect was observed and latencies were substantially faster than in the 'normal' PWI task of Experiment 1. In Experiment 3 we present a further test of the grammatical class and relative speed accounts.

Experiment 3 – Stroop paradigm with colour words

Another way to distinguish between the grammatical class and relative speed accounts is to slow down naming latencies in the Stroop paradigm. Assuming we could slow down colour name retrieval in the Stroop task, the grammatical class account predicts no distractor frequency effect in Stroop, since the targets and distractors are from different grammatical classes. By contrast, under these conditions, the relative speed account predicts the appearance of a distractor frequency effect, given that by slowing down colour name retrieval the distractor word is processed 'on time'.

One way to slow down colour name retrieval is to rely on the logic used in Experiment 2, and increase the number of colour targets in the Stroop task. However, it is impossible to include 20 colours in the Stroop paradigm, as 20 colours are hard to identify. Therefore, we opted for an alternative way to slow down colour naming in the Stroop task. As documented repeatedly across a variety of tasks (Kinoshita, Mozer & Forster, 2011; Meyer, Roelofs, & Levelt, 2003; Rastle, Kinoshita, Lupker, & Coltheart, 2003; Taylor & Lupker, 2001; see also Taylor & Lupker, 2007 for review) latencies to a given set of stimuli are faster when those stimuli are presented in the context of comparably easy stimuli than when presented in the context of comparably hard stimuli. This effect is thought to occur in order to optimally initiate responses (Kinoshita et al., 2011; cf. Taylor & Lupker, 2007), but the mechanism underlying this response criterion shift is still debated (e.g., Kello & Plaut, 2000, 2003; Kinoshita et al., 2011; Kinoshita & Mozer, 2006; Lupker, Kinoshita, Coltheart, & Taylor, 2003; Meyer et al., 2003; Rastle et al., 2003; Taylor & Lupker, 2001, 2006, 2007). In order to induce a slowdown in colour naming, we included a set of congruent and incongruent colour distractor words in the experiment, given that incongruent colour words (different colour words and colour targets) produce a large interference effect compared to congruent colour words (same colour words and colour targets) or a neutral condition (around 100 ms, e.g., Dunbar & MacLeod, 1984; Glaser & Glaser, 1982, 1989). We expected that the inclusion of these colour words increases the difficulty of the task and shifts participants' response criterion to a point where the colour-naming response is delayed. In turn, this leads to a change in the speed of processing of the colour name relative to the distractor word such that distractor words now arrive 'on time', meaning that they interfere with the colour-naming response.[2] In addition, we not only included the incongruent distractor words, but also congruent distractor words to measure the basic Stroop effect. If grammatical class plays a crucial role in determining the presence of the distractor frequency effect we expected no effect in Experiment 3. Similarly, the explanation in terms of non-standard target retrieval also predicts no effect of distractor frequency in Experiment 3 as there is high repetition of the target responses. By contrast, if the relative speed of target and distractor word processing plays a crucial role, we expected to observe the distractor frequency and Stroop effects in Experiment 3.

Method

Participants

Twenty-four native English speakers (7 male) took part in Experiment 3.

Materials

We used the same high-/low-frequency word distractors from Experiments 1 and 2. We included the standard Stroop conditions consisting of four colour words (red, blue, green and yellow) divided into two conditions: (1) a congruent condition: the colour and the word matched; and (2) an incongruent condition: the colour and the word did not match (e.g., the word 'red' printed in blue ink). The incongruent condition was included to slow down colour naming in the frequency conditions and the congruent condition was to verify that the standard Stroop effect was obtained in this experiment. There were 80 fillers so that the colour congruency conditions (congruent and incongruent) only occurred 1/3 of the time. They were non-colour words and not used in the frequency conditions. This manipulation was introduced to rule out the possibility that participants expected colour words when performing the naming task. No colour name shared the same phonological onset as a written word (except in the congruent colour condition). The 40 high- and low-frequency words were each seen once, while the colour words were seen 20 times each (10 times in the congruent condition and 10 times in the incongruent condition). We repeated the control condition 20 times in order to get the enough power for the standard Stroop effect (Kieley & Hartley, 1997; Klopfer, 1996).

Design and procedure

The four conditions (40 high-frequency and 40 low-frequency words, 4 incongruent and congruent colour words) and 80 fillers were combined into six blocks, each containing approximately six experimental trials for each distractor condition (high/low frequency and incongruent/congruent) and filler. Each block was 40 trials long. Trial presentation within each block was pseudo-randomised such that no print colour or word was repeated on consecutive trials and the colour denoted by a word and the colour of the printed word were different on consecutive trials. Each subject saw all six blocks, and the order of block presentation was counterbalanced across subjects. Three warm-up trials using practice items were included at the beginning of each block. The procedure was identical to the Stroop paradigm in the Experiment 1. The experiment lasted for 15 minutes.

Results

Latency data were preprocessed in the same way as Experiment 1; 4.6% (including 3.1% errors) of the data points were removed. An overview of the mean RTs and error rates for each of the four conditions is presented in Table 3.

There was no significant distractor frequency effect in the error analysis (χ^2 (1) = 1.37, p = 0.24), but there were more errors for incongruent colour words compared to congruent colour words (χ^2 (1) = 17.34, $p < 0.001$), and the increased odds ratio for making an error in the incongruent relative to congruent condition was 3.31. In the analysis of naming latencies, two paired-samples t-tests were computed comparing high- and low-frequency words (for the subject analysis) and congruent and incongruent words. An unpaired-samples t-test was computed comparing high- and low-frequency words for the item analysis. Naming latencies were 16 ms slower for low-frequency distractors than high-frequency distractors (t_1 (23) = 4.44, $p < 0.001$; t_2 (78) = 5.09, $p < 0.001$). Naming latencies were 127 ms slower for incongruent colour words than congruent colour words (t_1 (23) = 10.25, $p < 0.001$; t_2 (78) = 14.05, $p < 0.001$). In sum, we observed both the distractor frequency effect and the standard Stroop effect in the Stroop paradigm.

Discussion

For the first time we observed a significant distractor frequency effect in a Stroop paradigm. This effect was observed in the context of a basic Stroop effect. In addition, the overall response times in this experiment were significantly slower than for the Stroop paradigm in Experiment 1a (t (46) = 3.90, $p < 0.001$). This result is consistent with the relative speed account where contrasting effects of distractor frequency in the PWI and Stroop paradigms are caused by differences in the speed with which picture and colour names are processed relative to distractor words. It is inconsistent with the grammatical

Table 3. Naming latencies (ms) and error rates (in the parentheses) for the four conditions in Experiments 3 and 4.

	Incongruent colour words	Congruent colour words	Difference[a]	LF words	HF words	Difference[b]
Exp. 3 (Stroop)	794 (0.09)	667 (0.03)	127*	705 (0.02)	689 (0.03)	16*
Exp. 4 (Stroop)	830 (0.07)	717 (0.04)	113*	725 (0.03)	705 (0.03)	20*
Exp. 4 (PWI)	–	–	–	703 (0.04)	684 (0.03)	19*

LF, low frequency; HF, high frequency.
[a]Difference between incongruent and congruent colour words.
[b]Difference between LF and HF word distractors.
*$p < 0.05$.

class account, as this account predicts no distractor frequency effect in this experiment, since the targets and distractors are from different grammatical classes. In sum, in Experiments 2 and 3, we established that the relative speed account best predicts the contrasting results in Experiment 1 and ruled out other alternatives.

Given that this is the first time that a reliable distractor frequency effect is observed in the Stroop paradigm, it is important to establish the robustness of this effect. Our primary goal in Experiment 4 was to replicate the distractor frequency effect in the Stroop task when colour distractor words were present in the experiment. In addition, we wanted to directly compare the size of the distractor frequency effect between PWI and Stroop paradigms within the same set of participants, assuming that different distractor frequency effect sizes may indicate different mechanisms underlie this effect. In Experiment 4, we used the same high- and low-frequency distractor words in both paradigms within a new group of participants.

Experiment 4 – replication of Experiment 3

Method

Participants

Twenty-four native English speakers (14 male) took part in Experiment 4.

Materials and procedure

For the Stroop paradigm, we used the same materials and design from Experiment 3. For the PWI paradigm we used the same materials and design of the PWI paradigm in Experiment 1a. There were four conditions (40 high-frequency and 40 low-frequency words, 4 incongruent and congruent colour words) in the Stroop paradigm and two conditions (40 high- and 40 low-frequency words) in the PWI paradigm. The procedure was the same as that in Experiment 1a. The experiment lasted for 30 minutes.

Results and discussion

Latency data were preprocessed in the same way as Experiment 1. For the Stroop paradigm, 4.0% (including 2.5% errors) of the data points were removed. For the PWI paradigm, 3.3% (including 1.4% errors) of the data points were removed. There was no significant distractor frequency effect in errors in either Stroop or PWI paradigms (Stroop: χ^2 (1) = 0.10, p = 0.75; PWI: χ^2 (1) = 0.63, p = 0.43). But in the Stroop paradigm, there was a significantly higher error rate for incongruent colour words compared to congruent colour words (χ^2 (1) = 7.5, $p < 0.01$), and the increased odds ratio for making an error in the incongruent relative to congruent condition was 1.91. In the analysis of naming latencies, two ANOVAs were computed with participants and items as random variables and a paired-samples t-test was computed comparing colour naming with incongruent and congruent colour words. Fixed variables were distractor frequency condition (high frequency vs. low frequency) which was a within-subject and between-item variable and paradigm type (Stroop vs. PWI) which was a within-subject and within-item variable. There was a main effect of the distractor frequency (F_1 (1, 23) = 41.37, $p < 0.001$, MSE = 214.11; F_2 (1, 78) = 11.41, $p < 0.001$, MSE = 1263.25), indicating slower target-naming latencies in the context of low-frequency words than high-frequency words. There was no difference between colour naming in the Stroop paradigm and picture naming in the PWI paradigm (F_1 (1, 23) = 1.04, p = 0.32, MSE = 10,540.73; F_2 (1, 78) = 12.30, p = 0.001, MSE = 1418.99). The interaction between frequency condition and paradigm was not significant (F's < 1). In the Stroop paradigm, naming latencies were significantly slower (113 ms) in the context of incongruent colour words than congruent colour words (t_1 (23) = 9.25, $p < 0.001$; t_2 (78) = 12.03, $p < 0.001$).

To demonstrate that task 1 did not have an effect on task 2 (e.g., Allport et al., 1994), we also tested whether there was an interaction between task order (first vs. second) and frequency (high vs. low) in the two paradigms. In both paradigms, there was no interaction between order and frequency (Stroop: F's < 1; PWI: F_1 (1, 22) = 1.33, p = 0.26, MSE = 229.33; F_2 < 1).

In sum, the results establish the reliability of the presence of the distractor frequency effect in a Stroop paradigm with colour word distractors and also show that when naming is slow, the distractor frequency effects in both Stroop and PWI paradigms are comparable. This pattern is consistent with the relative speed account which assumes that when naming is slow, distractor words reach the buffer/perceptual input before pictures/colours, leading to a distractor frequency effect and similar patterns for both Stroop and PWI paradigms.

General discussion

In this study we explored whether the Stroop and PWI paradigms operate in a similar way by comparing the distractor frequency effect (i.e., picture-naming latencies are slower in the presence of low-frequency distractor words compared to high-frequency distractor words) in the Stroop and PWI paradigms. Previous studies have shown a robust distractor frequency effect in PWI but not in Stroop (Dhooge & Hartsuiker, 2010, 2011; Miozzo & Caramazza, 2003; Monsell et al., 2001). We conducted four experiments to explore whether the contrasting distractor frequency effects were due to methodological differences in previous studies, or alternatively, whether they are caused by design differences that are inherent in the Stroop and PWI tasks.

In Experiment 1, using a within-participant and within-materials design, we observed the distractor frequency effect in the standard PWI paradigm, but not in the Stroop paradigm. This result rules out that different participants and materials account for the previously observed contrast in distractor frequency effects between paradigms. In subsequent experiments we focused on distinguishing between an explanation of these contrasting effects between Stroop and PWI tasks in terms of differences related to grammatical class, stimulus display and variables that impact the relative speed of processing target and distractor words in the two tasks. Our data support the relative speed account. Specifically, we successfully manipulated the appearance and disappearance of the distractor frequency effect in both the PWI and Stroop paradigms by changing the relative speed of processing between target and distractor. In Experiment 2, the distractor frequency effect was eliminated in the PWI paradigm by speeding up picture naming through changing response set size and response repetition. In Experiment 3, the distractor frequency effect was observed in the Stroop paradigm when naming latencies were slowed down by including colour words as distractors in the experiment. In Experiment 4 we replicated the results of Experiment 3 and showed that when naming speed was equated between the two paradigms, a similar sized distractor frequency effect emerges. Thus the results suggest that the contrasting effects of distractor frequency between Stroop and PWI tasks are caused by differences in the relative speed of processing target and distractor stimuli in the two tasks.

The relative speed account in combination with the Response Exclusion Hypothesis or WEAVER ++ provides a unifying account of the contrasting effects of distractor frequency between Stroop and PWI tasks. The observation of a distractor frequency effect in the Stroop or PWI task reflects the situation where the distractor word is processed 'on time'. This means that processes related to the distractor interfere with those related to the target. In the Response Exclusion Hypothesis, this may be implemented by assuming that the distractor word occupies the articulatory buffer during a time window when it is actively preventing the target response from entering into the buffer. Under such conditions, the time that the distractor occupies the buffer directly impacts naming latencies, leading to the observed distractor frequency effect. Similarly, in WEAVER++, 'on time' processing of the distractor word may be implemented by assuming that attentional control processes depend on the type of stimuli, such that with picture–word stimuli, the word is processed sufficiently to impact target processing, leading to the observed distractor frequency effect.

By contrast, when no distractor word frequency effect is observed in the Stroop or PWI task, the distractor word is processed 'too late'. This means that processes related to the distractor do not interfere with those related to the target. There are two distinct scenarios that could produce such an absence of the effect. First, distractor processing takes place *after* target processes have already finished. In the response exclusion hypothesis, this could be implemented by assuming that the distractor word enters the articulatory buffer *after* target processing in the buffer has already finished, leading to the absence of the distractor frequency effect. Similarly, in WEAVER++ this may be implemented by assuming that attentional control processes diminish processing of the distractor word such that they no longer impact target word processing. Alternatively, the absence of the distractor frequency effect may reflect the situation in which all distractor word processes have finished *before* any target word processes have commenced (i.e., when target processing is delayed or extremely slow) (e.g., Dhooge & Hartsuiker, 2010, Experiment 3, SOA = 300 ms). In the Response Exclusion Hypothesis, this reflects the situation in which the distractor word is rejected from the output buffer prior to the critical time window during which it prevents the target response from entering the buffer. In WEAVER++, this could be implemented by assuming that distractor processes take place with a sufficient temporal delay from target processes (see Dhooge & Hartsuiker, 2010, and Roelofs, Piai, & Schriefers, 2011 for further discussion on this issue). Thus, in order to account for the contrasting results of distractor frequency in the Stroop and PWI tasks, both the Response Exclusion Hypothesis and WEAVER++ need to take into account the assumption that processing in these two tasks depends on the relative speed of processing.

A direct test of the relative speed account is to examine the distribution of response latencies across all four experiments.[3] According to this account, the distractor frequency effect should disappear when overall response latencies are faster or extremely slow, but should show up when response latencies are in between. Following Ratcliff (1979), we ranked response latencies for each participant and then divided the participant's latencies into 10 bins. Mean participant's latencies were computed for each bin and for each condition. Using the same procedure, the response latency distribution was also obtained based on the rank-ordered latencies for the high- and low-frequency distractor words. For each high- and low-frequency distractor word, the ranked-ordered latencies across all the subjects were divided into 10 bins. The interaction between frequency and bin was significant (F_1 (9, 1467) = 2.98, p = 0.002, MSE = 815.92; F_2 (9, 702) = 2.28, p = 0.02, MSE = 483.66, see Figure 2) suggesting that the frequency effect (difference between low- and high-frequency distractors) changed depending on whether the response latencies were fast or slow. The distractor frequency effect was not significant at the fastest (bin 1: 4 ms, t_1 (163) = 1.04, p = 0.30; t_2 (78) = 0.40, p = 0.69;

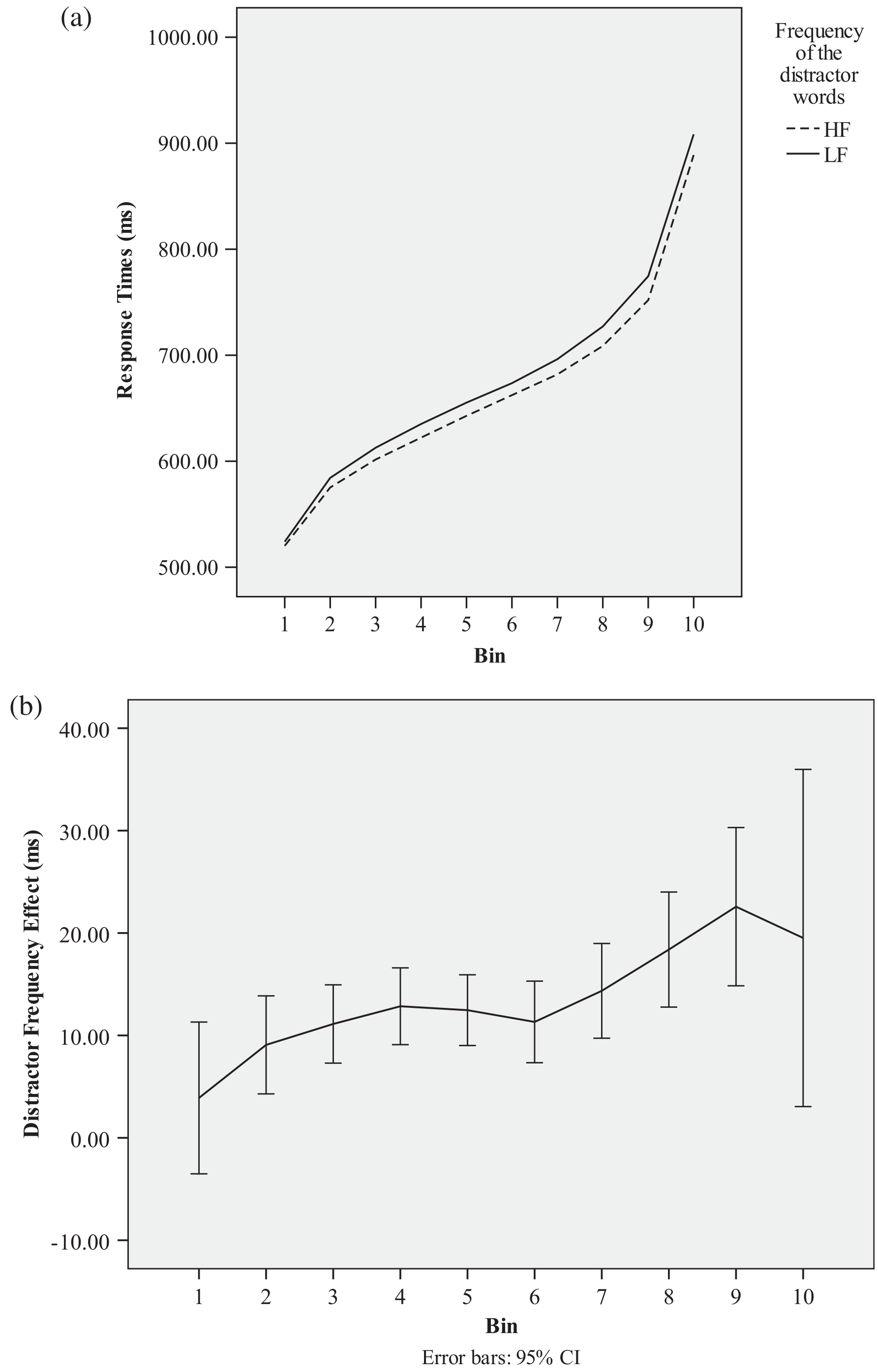

Figure 2. (a) The cumulative distribution curves for response times in the high-frequency (HF) and low-frequency (LF) word distractor conditions for Experiments 1–4 with response times divided into 10 bins, from fastest (bin 1) to slowest (bin 10). (b) The change of the distractor frequency effect (low frequency–high frequency) across RTs divided into 10 bins, from fastest RTs (bin 1) to slowest RTs (bin 10). The error bars indicate the 95% confidence intervals derived from the variance across participants.

marginal in bin 2: 9 ms, t_1 (163) = 3.74, $p < 0.001$; t_2 (78) = 1.92, p = 0.06) and slowest (marginal in bin 10: 19 ms, t_1 (163) = 2.34, p = 0.02; t_2 (78) = 1.91, p = 0.06) latencies, but was significant in the middle latencies (bins 3–9: p's < 0.05). Furthermore, when we separated the original RTs in bin 10 into two subgroups, we observed the distractor frequency effect (t_1 (163) = 3.44, $p < 0.001$; t_2 (78) = 2.00, p = 0.05) in the subgroup with faster RTs but no distractor frequency effect (t_1 (163) = 1.42, p = 0.16; t_2 (78) = 1.72, p = 0.09) in the subsequent slower RT subgroup. Thus, consistent with the proposed relative speed account, the distractor frequency effect was not observed when naming was relatively fast (bins 1–2; distractor processing takes place after target processes finish), occurred when the distractor word was processed 'on time' relative to the target (bins 3–9) and disappeared for very long naming latencies in bin 10, when all distractor word processes have finished before any target word processes have commenced (relatively slow picture naming).

Our conclusion that performance in the PWI and Stroop tasks crucially depends on the relative speed of processing a target and distractor needs to be reconciled with previous arguments that have been made against a relative speed model of the Stroop effect. Three decades ago, a horse race account similar to our relative speed account was proposed to account for the Stroop effect (Klein, 1964; Morton & Chambers, 1973). The horse race model has two key assumptions. First, in the Stroop paradigm, word reading and colour naming occur in parallel, and word reading is faster than colour naming. Second, there is a single-channel output buffer which can be occupied by only one of the two potential responses (word or colour) at a time. Priority is determined by speed. Given that word reading is faster than colour naming, the distractor word occupies the output buffer before the colour name is available. Clearing of this buffer must therefore take place before colour word production can occur. It explains the Stroop effect by assuming that due to response competition between the incongruent distractor word and the ink colour, it takes longer to clear incongruent than congruent distractors from the buffer (e.g., Morton & Chambers, 1973). In other words, the horse race account assumes that the *only thing* that matters in determining performance in the Stroop task is the relative speed of the target and word response. However, several studies have revealed problems with such a one-factor explanation of the Stroop effect. Specifically, if relative speed determines the Stroop effect, one expects an interference effect under conditions where participants read a colour word 400 ms *after* the presentation of an incongruent colour patch, as the colour name occupies the buffer *before* the target word. However, under these conditions no interference effect is observed (Glaser & Glaser, 1982). Likewise, other studies show that when reading is made dramatically slower than colour naming by using transformed words (e.g., upside-down-and-backwards words), the Stroop effect in colour naming persists virtually unaltered (Dunbar & MacLeod, 1984). These studies have been interpreted against the horse race model.

The previous evidence against the horse race model rules out the explanation in which speed is the *only factor* which determines performance in Stroop and PWI, but it does not rule out a *multi-factor* model in which speed is a factor alongside other factors determining the effects in Stroop and PWI. An important aspect of our relative speed explanation of performance is that it is not the primary mechanism for the various observed effects. Similarly, some models in language production also suggest that speed plays a key role in the Stroop and PWI performances. For example, Dunbar and MacLeod (1984) argued that a horse race model with multiple factors (i.e., speed and priming) was able to interpret their results. They interpreted the failure to eliminate the standard Stroop effect by making word reading slower than colour naming as due to the priming of the colour words in the Stroop task. They argued that the word reading response times did not reflect how long it takes to identify the distractor words in a colour-naming (Stroop) task. This is because in their word reading task, there were a large number of words to read (120), whereas in their colour-naming task, a very small number of colours to name (5) and a large number of repetitions of the five colour names. This leads to a lower threshold of activation for these five colour words, resulting in faster recognition for these colour words in the colour-naming task, thus explaining why the Stroop effect persisted in their study. They also stated that speed still played a role in their model, as colour names interfered with word reading when word reading was extremely slow. Thus, our proposal that speed of processing affects performance in the Stroop and PWI tasks is consistent with earlier accounts. Moreover, more recent accounts such as WEAVER++ also assume that the speed of processing plays an important role (see Roelofs, 2003). Therefore, we argue that the relative speed between target and distractor processing plays a role in explaining interference effects in the Stroop and PWI paradigms and that current accounts of the distractor frequency effect need to incorporate the assumption of the relative speed of processing to explain the results reported here.

If performance in these tasks is determined by speed of processing, a crucial question concerns which factors affect the speed of processing in these two paradigms. As demonstrated here, a small response set accompanied by high repetition reduces naming latencies (Experiments 1–2), while the inclusion of colour words from the response set increases naming latencies (Experiments 3–4). Previous studies show that stimuli's frequency, age of acquisition, familiarity and visual complexity impact naming speed (e.g., Barry, Morrison, & Ellis, 1997; Cycowicz, Friedman, Rothstein, & Snodgrass, 1997), as well as whether targets are error-prone (Kinoshita & Mozer, 2006). As described in the discussion of Experiment 3, attention may also play a role in modulating the speed of processing of the target and distractor word. A future goal of this work is to clarify the relationship between attention and speed in the Stroop and PWI paradigms.

Conclusions

In sum, this study firmly establishes the finding that the speed of naming colours and pictures affects the appearance of the distractor frequency effect in PWI and Stroop tasks. The assumption that speed of processing matters in these tasks is compatible with both the Response Exclusion Hypothesis (Mahon et al., 2007) and WEAVER++ (Roelofs, 2003). Within the context of response exclusion, factors affecting speed of processing may cause a distractor word to appear in the buffer 'too late' thereby missing the crucial time window in which target production can be affected. Similarly, within the context of WEAVER++, distractors may appear 'too late' to affect perceptual blocking, also leaving target production unaffected.

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Notes

1. Following Ulrich and Miller (1994), we also performed *t*-test and ANOVA analyses of RTs on the untrimmed data (i.e., the latency data included RTs more than three standard deviations away from the mean), for all comparisons across Experiments 1–4. For all comparisons, trimmed and untrimmed statistical analyses produced the same pattern of significant and non-significant effects at the $p < 0.05$ level.
2. RTs slow down for easy trials but not to the degree that they match the difficult trials (see Kinoshita & Mozer, 2006, Lupker, Brown, & Colombo, 1997).
3. We combined all experiments for the RT distribution analysis, as the power to detect effects was small for each experiment (around 0.18), and much larger when experiments were combined (0.72). Following Ulrich and Miller (1994), we presented a distribution analysis on the untrimmed data (i.e., the latency data including those that are more than three standard deviations away from the mean). Whether the distribution analysis was with trimmed or untrimmed data, we found similar results which are consistent with our predictions (i.e., no distractor frequency effect when naming is fast and a significant distractor frequency effect when naming is relatively slow).

References

Abdel Rahman, R., & Aristei, S. (2010). Now you see it… and now again: Semantic interference reflects lexical competition in speech production with and without articulation. *Psychonomic Bulletin & Review*, *17*, 657–661. doi:10.3758/PBR.17.5.657

Agresti, A. (2002). *Categorical data analysis*. New York, NY: John Wiley & Sons.

Allport, D. A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umiltà & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconscious information processing* (pp. 421–452). Cambridge, MA: MIT Press.

Barry, C., Morrison, C. M., & Ellis, A. W. (1997). Naming the Snodgrass and Vanderwart pictures: Effects of age of acquisition, frequency, and name agreement. *Quarterly Journal of Experimental Psychology*, *50A*, 560–585.

Burt, J. S. (1994). Identity primes produce facilitation in a colour naming task. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *47*, 957–1000. doi:10.1080/14640749408401103

Burt, J. S. (2002). Why do non-color words interfere with color naming? *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 1019–1038. doi:10.1037/0096-1523.28.5.1019

Cohen, J. D., Dunbar, K., & McClelland, I. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review*, *97*, 332–361. doi:10.1037/0033-295X.97.3.332

Coltheart, M. (1981). The MRC psycholinguistic database. *The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, *33*, 497–505. doi:10.1080/14640748108400805

Cycowicz, Y. M., Friedman, D., Rothstein, M., & Snodgrass, J. G. (1997). Picture naming by young children: Norms for name agreement, familiarity, and visual complexity. *Journal of Experimental Child Psychology*, *65*, 171–237. doi:10.1006/jecp.1996.2356

Dhooge, E., & Hartsuiker, R. J. (2010). The distractor frequency effect in picture-word interference: Evidence for response exclusion. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*, 878–891. doi:10.1037/a0019128

Dhooge, E., & Hartsuiker, R. J. (2011). The distractor frequency effect in a delayed picture-word interference task: Further evidence for a late locus of distractor exclusion. *Psychonomic Bulletin & Review*, *18*, 116–122. doi:10.3758/s13423-010-0026-0

Dunbar, K., & MacLeod, C. M. (1984). A horse race of a different color: Stroop interference patterns with transformed words. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 622–639. doi:10.1037/0096-1523.10.5.622

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, and Computers*, *35*(1), 116–124. doi:10.3758/BF03195503

Fox, L. A., Shor, R. E., & Steinman, R. J. (1971). Semantic gradients and interference in naming color, spatial direction, and numerosity. *Journal of Experimental Psychology*, *91*(1), 59–65. doi:10.1037/h0031850

Glaser, W. R., & Düngelhoff, F. J. (1984). The time course of picture-word interference. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 640–654. doi:10.1037/0096-1523.10.5.640

Glaser, M. O., & Glaser, W R. (1982). Time course analysis of the Stroop phenomenon. *Journal of Experimental Psychology: Human Perception and Performance*, *8*, 875–894. doi:10.1037/0096-1523.8.6.875

Glaser, W. R., & Glaser, M. O. (1989). Context effects in Stroop-like word and picture processing. *Journal of Experimental Psychology: General*, *118*, 13–42. doi:10.1037/0096-3445.118.1.13

Hantsch, A., & Mädebach, A. (2011). What does the articulatory output buffer know about alternative picture names?

Evidence against the response-exclusion hypothesis. *Language and Cognitive Process*, *28*, 684–700.

Janssen, N. (2013). Response exclusion in word–word tasks: A comment on Roelofs, Piai and Schriefers. *Language and Cognitive Processes*, *28*, 672–678. doi:10.1080/01690965.2012.746715

Janssen, N., Melinger, A, Mahon, B. Z., Finkbeiner, M., & Caramazza, A. (2010). The word class effect in the picture–word interference paradigm. *The Quarterly Journal of Experimental Psychology*, *63*, 1233–1246. doi:10.1080/17470210903377380

Kahan, A. T., & Hely, D. C. (2008). The role of valence and frequency in the emotional Stroop task. *Psychonomic Bulletin & Review*, *15*, 956–960. doi:10.3758/PBR.15.5.956

Kello, C. T., & Plaut, D. C. (2000). Strategic control in word reading: Evidence from speeded responding in the tempo-naming task. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *26*, 719–750. doi:10.1037/0278-7393.26.3.719

Kello, C. T., & Plaut, D. C. (2003). Strategic control over rate of processing in word reading: A computational investigation. *Journal of Memory & Language*, *48*, 207–232. doi:10.1016/S0749-596X(02)00512-0

Kieley, J. M., & Hartley, A. A. (1997). Age-related equivalence of identity suppression in the Stroop color-word task. *Psychology and Aging*, *12*(1), 22–29. doi:10.1037/0882-7974.12.1.22

Kinoshita, S., & Mozer, M. C. (2006). How lexical decision is affected by recent experience: Symmetric versus asymmetric frequency-blocking effects. *Memory & Cognition*, *34*(3), 726–742. doi:10.3758/BF03193591

Kinoshita, S., Mozer, M., & Forster, K. I. (2011). Dynamic adaptation to history of trial difficulty explains the effect of congruency proportion on masked priming. *Journal of Experimental Psychology: General*, *140*, 622–636. doi:10.1037/a0024230

Klein, G. S. (1964). Semantic power measured through the interference of words with color naming. *American Journal of Psychology*, *77*, 576–588. doi:10.2307/1420768

Klopfer, D. S. (1996). Stroop Interference and color-word similarity. *Psychology Science*, *7*, 150–157. doi:10.1111/j.1467-9280.1996.tb00348.x

Lupker, S. J. (1979). The semantic nature of response competition in the picture-word interference task. *Memory & Cognition*, *7*, 485–495. doi:10.3758/BF03198265

Lupker, S. J., Brown, P., & Colombo, L. (1997). Strategic control in a naming task: Changing routes or changing deadlines? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *23*, 570–590. doi:10.1037/0278-7393.23.3.570

Lupker, S. J., Kinoshita, S., Coltheart, M., & Taylor, T. (2003). Mixing costs and mixing benefits in naming words, pictures, and sums. *Journal of Memory & Language*, *49*, 556–575. doi:10.1016/S0749-596X(03)00094-9

Mädebach, A., Oppermann, F., Hantsch, A., Curda, C., & Jescheniak, J. D. (2011). Is there semantic interference in delayed naming? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*, 522–538. doi:10.1037/a0021970

Mahon, B. Z., Costa, A., Peterson, R., Vargas, K., & Caramazza, A. (2007). Lexical selection is not by competition: A reinterpretation of semantic interference and facilitation effects in the picture-word interference paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*, 503–535. doi:10.1037/0278-7393.33.3.503

Meyer, A. S., Roelofs, A., & Levelt, W. J. M. (2003). Word length effects in object naming: The role of a response criterion. *Journal of Memory & Language*, *48*, 131–147. doi:10.1016/S0749-596X(02)00509-0

Miozzo, M., & Caramazza, A. (2003). When more is less: A counterintuitive effect of distractor frequency in picture–word interference paradigm. *Journal of Experimental Psychology: General*, *132*, 228–252. doi:10.1037/0096-3445.132.2.228

Monsell, S., Taylor, T. J., & Murphy, K. (2001). Naming the color of a word: Is it responses or task sets that compete? *Memory & Cognition*, *29*, 137–151. doi:10.3758/BF03195748

Morton, J., & Chambers, S. M. (1973). Selective attention to words and colours. *Quarterly Journal of Experimental Psychology*, *25*, 387–397. doi:10.1080/14640747308400360

Mulatti, C., & Coltheart, M. (2012). Picture-word interference and the response exclusion hypothesis. *Cortex*, *48*, 363–372. doi:10.1016/j.cortex.2011.04.025

Navarrete, E., & Mahon, B. (2013). A rose by any other name is still a rose: A reinterpretation of Hantsch and Mädebach. *Language and Cognitive Processes*, *28*, 701–716.

Pechmann, T., Garrett, M., & Zerbst, D. (2004). The time course of recovery for grammatical class information during lexical processing for syntactic construction. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*, 723–728. doi:10.1037/0278-7393.30.3.723

Pechmann, T., & Zerbst, D. (2002). The activation of word class information during speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 233–243. doi:10.1037/0278-7393.28.1.233

Piai, V., Roelofs, A., & Schriefers, H. (2011). Semantic interference in immediate and delayed naming and reading: Attention and task decisions. *Journal of Memory and Language*, *64*, 404–423. doi:10.1016/j.jml.2011.01.004

Rastle, K., Kinoshita, S., Lupker, S. J., & Coltheart, M. (2003). Cross-task strategic effects. *Memory & Cognition*, *31*, 867–876. doi:10.3758/BF03196441

Ratcliff, R. (1979). Group reaction time distributions and an analysis of distribution statistics. *Psychological Bulletin*, *86*, 446–461. doi:10.1037/0033-2909.86.3.446

Roelofs, A. (2003). Goal-referenced selection of verbal action: Modeling attentional control in the Stroop task. *Psychological Review*, *110*, 88–125. doi:10.1037/0033-295X.110.1.88

Roelofs, A. (2005). From Popper to Lakatos: A case for cumulative computational modeling. In A. Cutler (Ed.), *Twenty-first century psycholinguistics: Four cornerstones* (pp. 313–330). Hillsdale, NJ: LEA.

Roelofs, A., Piai, V., & Schriefers, H. (2011). Selective attention and distractor frequency in naming performance: Comment on Dhooge and Hartsuiker (2010). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*, 1032–1038. doi:10.1037/a0023328

Roelofs, A., Piai, V., & Schriefers, H. (2013). Context effects and selective attention in picture naming and word reading: Competition versus response exclusion. *Language and Cognitive Processes*, *28*, 655–671.

Rosinski, R. R., Golinkoff, R. M., & Kukish, K. S. (1975). Automatic semantic processing in a picture-word interference task. *Child Development*, *46*, 247–253. doi:10.2307/1128859

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*, 174–215. doi:10.1037/0278-7393.6.2.174

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662. doi:10.1037/h0054651
Taylor, T. E., & Lupker, S. J. (2001). Sequential effects in naming: A time-criterion account. *Journal of Experimental Psychology: Learning, Memory and Cognition 27*(1), 117–138. doi:10.1037/0278-7393.27.1.117
Taylor, T. E., & Lupker, S. J. (2006). Time perception and word recognition: An elaboration of the time-criterion account. *Perception & Psychophysics*, *68*, 933–945. doi:10.3758/BF03193356
Taylor, T. E., & Lupker, S. J. (2007). Sequential effects in time perception. *Psychonomic Bulletin & Review*, *14*(1), 70–74. doi:10.3758/BF03194030
Ulrich, R., & Miller, J. (1994). Effects of truncation on reaction time. *Journal of Experimental Psychology: General*, *123*(1), 34–80. doi:10.1037/0096-3445.123.1.34
Vigliocco, G., Vinson, D. P., & Siri, S. (2005). Semantic similarity and grammatical class in naming actions. *Cognition*, *94*, B91–B100. doi:10.1016/j.cognition.2004.06.004

Appendix 1

The 40 high-frequency and 40 low-frequency words used in all experiments and 20 pictures used in Experiments 1a and 4. Four pictures were used as targets in Experiment 2: PIG, TREE, CAR, HAT. Four colours were used as both distractors and targets in Experiments 3 and 4 and used only as targets in all Stroop tasks: GREEN, RED, BLUE, YELLOW.

Pictures	High-frequency words	Low-frequency words	High-frequency words	Low-frequency words
Anchor	music	coral	paper	comet
Arrow	plant	frock	light	torch
Bell	city	lava	eye	ewe
Candle	street	strait	field	pouch
Cup	body	tofu	river	tulip
Drum	water	camel	woman	bacon
Duck	house	gnome	child	clown
Fish	night	marsh	church	crutch
Flag	dog	key	hair	loaf
Foot	town	vest	court	vault
Hat	table	valve	air	owl
Kite	school	spleen	hand	fern
Lemon	voice	crate	money	patio
Necklace	fire	dove	food	quiz
Pear	gun	hog	cell	cask
Pepper	head	bait	war	wig
Pig	name	bale	girl	harp
Pipe	horse	badge	wall	cuff
Rope	office	alcove	doctor	pulpit
Tent	class	scalp	book	reel