Semantic picture–word interference is a postperceptual effect

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Abstract Naming a picture is slower while ignoring a semantically related versus an unrelated distractor word (semantic picture–word interference, or PWI). To locate the PWI effect in the word production processing stream (during perceptual encoding, response selection, or afterward), we used the psychological refractory period paradigm, in which participants identified a tone and then, at varying SOAs, named a picture while ignoring a semantically related or unrelated word (following Dell’Acqua, Job, Peressotti, & Pascali, 2007). As in results from the Stroop paradigm (Fagot & Pashler, 1992), we found equivalent PWI effects at short and long SOAs following tone identification in two experiments, indicating that semantic competition occurs at response selection or later. Our results suggest that it is premature to assume that competitive selection occurs at multiple levels in the word production system (van Maanen, van Rijn, & Borst, 2009) or that the Stroop and semantic PWI effects are fundamentally different (Dell’Acqua et al., 2007).

Keywords Psychological refractory period · Speech production · Picture-word interference paradigm

In order to study word production, several well-studied methods have manipulated the difficulty with which we choose a word by increasing the availability of competitor words. We are generally slower when naming the presentation color of a word that spells a different color name (e.g., saying “black” when seeing WHITE vs. saying “black” when seeing

BLACK; i.e., Stroop interference: Stroop, 1935). Likewise, we are generally slower when naming a picture of a “dog” while concurrently seeing the displayed word RABBIT rather than the word TABLE (semantic interference in the picture–word interference paradigm; see, e.g., Lupker, 1979).

In both paradigms, the delay to choose the appropriate word to name is generally explained in similar ways (e.g., Roelofs, 2003). We are slower to produce the name (color/picture) in the presence of words that are semantically related rather than unrelated to the target because the related distractor words receive priming from both the target’s meaning and the printed distractor. Because the target name is selected on the basis of its activation level relative to the activation of other words in the lexicon, when competitors have increased activation, target selection takes more time (e.g., Roelofs, 1992; cf. Mahon, Costa, Peterson, Vargas, & Caramazza, 2007). This interference effect is thought not to occur during the identification of what meaning we need to convey (e.g., “black” or “dog”), but afterward, during response selection (Roelofs, 1992) or response execution (the prearticulatory buffer; Mahon et al., 2007).

One source of evidence for the response selection locus of the Stroop effect comes from the psychological refractory period (PRP) paradigm. The PRP paradigm can be used to determine where the components of task processing occur during performance—for example, during stimulus perception, or afterward, during the selection and execution of the appropriate response (Sternberg, 1969). In the PRP paradigm, participants perform two tasks in sequence and the onset delay between the stimuli for the two tasks is varied. The standard result is that response times (RTs) for the second task increase as the stimuli occur closer together in time (i.e., with decreasing stimulus onset asynchronies [SOAs]), whereas RTs for the first task remain constant. These results imply that there is a processing bottleneck such that some aspect of Task 1

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performance is completed prior to the completion of Task 2. Previous evidence has indicated that when the stimuli occur close together in time, parallel processing is possible during perceptual encoding; however, because response selection/execution occurs serially, response selection of Task 2 is delayed until response selection of Task 1 is completed (the bottleneck; Pashler, 1989; cf. Meyer & Kieras, 1997).

Using this logic, Fagot and Pashler (1992, Exp. 7) found evidence that Stroop interference is resolved during response selection. Participants listened to and identified one of two tones (Task 1). Following the tone at multiple SOAs, as Task 2, participants performed the Stroop task. Fagot and Pashler found equivalent Stroop interference at all delays following tone identification, indicating a response selection/execution locus (see Fig. 1 for the logic).

However, Dell'Acqua, Job, Peressotti, and Pascali (2007) carried out an experiment on picture–word interference (PWI) that followed the logic of Fagot and Pashler (1992), and they obtained findings suggesting a perceptual locus for such interference. Participants first identified a tone (Task 1) and, following variable SOAs, named pictures in the presence of semantically related and unrelated words. Semantic picture–word interference disappeared at the shortest, 100-ms SOA (a -7 -ms effect) and grew at the longer, 1,000-ms SOA (a 68-ms effect). Because picture RTs were not affected by semantic interference at short SOAs, this suggested that semantic interference was resolved during the perceptual encoding of Task 1, locating the effect prior to response selection/execution.

The findings of Dell'Acqua et al. (2007; replicated in part by Ayora et al., 2011) call into question previous results and theories across several domains (e.g., Cohen, Dunbar, & McClelland, 1990; MacLeod, 1991; Mahon et al., 2007; Roelofs, 2003) that have assumed a response selection or later locus for the Stroop and picture–word interference effects.¹ If the Dell'Acqua et al. (2007) conclusion that semantic interference occurs during perceptual encoding is upheld, as Dell'Acqua et al. aptly pointed out, “lexical selection accounts of PWI effect . . . can be hardly reconciled with the present empirical scenario” (2007, p. 720) and “models that do not rely on the notion of competition at the level of lexical selection do not appear to be more feasible in this respect either” (2007, p. 721). Furthermore, if semantic PWI is a perceptual effect (Dell'Acqua et al., 2007) and Stroop interference is a postperceptual effect (Fagot & Pashler, 1992), “. . . the conclusion that Stroop effects and PWI effects originate from distinct functional source[s] seems inescapable” (Dell'Acqua et al., 2007, p. 722).

¹ Elsewhere, McCann, Remington, and Van Selst (2000) and Lien, Ruthruff, Cornett, Goodin, and Allen (2008) provided PRP evidence that word processing requires central attention, findings that are also not consistent with the underadditive effects demonstrated by Dell'Acqua et al. (2007).

Fig. 1 Logic of the psychological refractory period paradigm. (A) If semantic interference (INT) occurs during perceptual encoding, encoding can proceed in parallel with response selection in Task 1 (T1: tone). Thus, when the delay is short (short delay = small SOA between Task 1 [tone] and Task 2 [color/picture naming]), no Task 2 semantic interference effect (semantically related [SR] – unrelated [UR]) is observed, because it is resolved during the cognitive slack, before response selection in Task 2 (color/picture naming) proceeds. (B) If semantic interference (INT) occurs during response selection or later, selection can occur only after response selection is completed for Task 1 (tone). Thus, when the delay is short between Task 1 (tone) and Task 2 (color/picture naming), a Task 2 semantic interference effect is observed, because the interference is resolved during response selection (or later) in Task 2 (color/picture naming)

Dell'Acqua et al.'s (2007) conclusions that semantic interference in naming occurs during perceptual encoding and that Stroop and PWI interference effects are fundamentally different are strong conclusions, given that they are based on one experiment. Given the potential importance of the implications of the Dell'Acqua et al. (2007) findings, we attempted to replicate their result in two experiments.

We used a variant of the PRP paradigm in which participants first identified one of three tones with a buttonpress and then, at varying SOAs, named a picture while ignoring a visually presented word that was semantically related or unrelated to the picture. If the semantic interference effect is a perceptual/conceptual retrieval effect and not subject to central processing mechanisms, we would expect an interaction between SOA and the semantic interference effect, with the size of the effect increasing with SOA (as seen by Dell'Acqua et al., 2007). Alternatively, if PWI occurs at response selection or later, we would expect interference to appear equally at all SOAs following the tone identification task (see Fig. 1 for this logic).

In Experiment 1a, we closely followed the Dell'Acqua et al. (2007) design, using the Dell'Acqua et al. (2007) stimuli, translated into English,² and nearly twice as many

² Thanks to Roberto Dell'Acqua for graciously giving us the stimulus materials from Dell'Acqua et al. (2007). Please contact the authors for our experimental stimuli.

participants. In Experiment 1b, we used a new set of stimuli and extended the longest SOA to 1,500 ms.

Experiment 1a

Method

Participants A group of 42 monolingual Rice University English-speaking undergraduates participated in the experiment, receiving class credit or monetary compensation. The participants provided Rice University–approved informed consent.

Materials The participants named 48 line drawings (Snodgrass & Vanderwart, 1980) from the stimuli list as used by Dell’Acqua et al. (2007), in the presence of either semantically related or unrelated words.

Apparatus Each picture was displayed on a white square against a black background, with word distractors centered in font size 32. We recorded vocal RTs via a headset with a microphone attached. Three keys on the computer keyboard were used to record buttonpress responses.

Design The experiment included two independent within-participants and within-items variables: distractor condition (semantically related or unrelated) and SOA (100, 350, or 1,000 ms). The 48 pictures and distractors were repeated six times, for a total of 288 experimental trials.

Procedure On each trial, the participant focused on a centered fixation cross for 1,000 ms. After 800 ms, the participants heard a randomly selected, 50-ms high-, middle-, or low-frequency tone (1,200, 600, or 300 Hz). Each participant pressed one of three keys—labeled “L,” “M,” or “H”—corresponding to the respective tone frequencies. The SOA between tone identification (Task 1) and picture naming (Task 2) was randomly varied between 100, 350, and 1,000 ms. After the delay, a picture with a superimposed word distractor was displayed, and the participant named the picture by speaking into the microphone on the headset. Buttonpress and naming RTs were recorded. We instructed participants to complete the tone identification prior to the picture naming.

Within the experiment, the combinations of SOA and tone were roughly equally represented, such that each tone was heard the same number of times for each SOA in each condition. Distractor condition and SOA were pseudorandomly assigned within each block, such that no more than three semantically related or same-SOA trials occurred in a

row, and no phonologically related pictures or identical distractors followed each other.

Before the experiment, participants named the pictures and afterward saw the picture names printed below the pictures. The participants then had 24 practice trials to train them on distinguishing the tones and naming pictures while ignoring distractors words. The experiment lasted 45 min.

Results

We carried out 2×3 analyses of variance (ANOVAs) by participants (F_1) and by items (F_2) on RTs and accuracy for both the tone identification and picture-naming tasks. Table 1 displays the mean RTs, error rates, and error ANOVA statistics, for both tone identification (Task 1) and picture naming (Task 2). Figure 2 displays the average RTs for both tasks at all SOAs and RT ANOVA statistics. Significant effects are discussed below.

Participants were 30 ms (95% confidence interval [CI]: 20–41 ms) slower to name pictures in the presence of semantically related rather than unrelated distractors. Picture-naming RTs decreased across the SOAs. The semantic interference effect remained stable across SOAs: on average, 30 ms (95% CI: 13–48 ms), 37 ms (95% CI: 19–54 ms), and 24 ms (95% CI: 7–42 ms) at the 100-, 350-, and 1,000-ms SOAs, respectively (see Fig. 2 and Table 1). The semantic interference effects across SOAs were not

Fig. 2 Experiment 1a results. SOA refers to the time between Stimulus 1 presentation (tone) and Stimulus 2 presentation (picture). ANOVA statistics include F1 analyses, in which Participants was a random factor, and F2 analyses, in which Items was a random factor. The picture-naming RT results showed significant differences for condition [$F_1(1, 36) = 35.61, p < .0001$; $F_2(1, 47) = 30.78, p < .001$] and SOA [$F_1(2, 72) = 782.47, p < .0001$; $F_2(2, 94) = 650.30, p < .0001$], with no other significant effects ($F_s < 1$). Tone identification RTs showed a significant effect of SOA [$F_1(2, 72) = 16.70, p < .0001$; $F_2(2, 94) = 10.88, p < .0001$] and no other significant effects ($ps < .15$). SR, semantically related distractor; UR, unrelated distractor

Table 1 Mean tone identification and picture-naming response times (RTs, in milliseconds; calculated from participant means, with standard deviations in parentheses) and error rates (as percentage means and standard errors) for each stimulus onset asynchrony (SOA) and distractor condition (SR or UR to picture)

Conditions	Tone Identification Response		Picture-Naming Response	
	Response Time	Error Rate	Response Time	Error Rate
SOA = 100 ms				
Related	587 (20)	7.2 (0.93)	1,041 (20)	1.2 (0.20)
Unrelated	581 (20)	6.0 (0.93)	1,011 (20)	1.1 (0.20)
Picture naming Δ (SR – UR) 30 ms		$t_1(72) = 3.42, p = .001; t_2(94) = 3.46, p < .001$		
SOA = 350 ms				
Related	573 (20)	6.2 (0.93)	891 (20)	0.42 (0.20)
Unrelated	569 (20)	5.1 (0.93)	854 (20)	0.54 (0.20)
Picture naming Δ (SR – UR) 37 ms		$t_1(72) = 4.20, p < .001; t_2(94) = 3.77, p < .001$		
SOA = 1,000 ms				
Related	562 (20)	5.5 (0.94)	795 (20)	0.31 (0.20)
Unrelated	556 (20)	5.2 (0.94)	771 (20)	0.31 (0.20)
Picture naming Δ (SR – UR) 24 ms		$t_1(72) = 2.73, p < .01; t_2(94) = 2.38, p < .01$		

We report t tests of the semantic interference effect (Δ) at each SOA. The t_1 statistics used Participants as the repeated factor, and the t_2 statistics used Items as the repeated factor. The analyses did not include trials with microphone errors for picture naming (6.5%) or trials on which Task 2 (picture naming) occurred erroneously before Task 1 (tone decision) (2.7%). Trials with either inaccurate tone discrimination (5.5%) or picture naming (2.7%) were eliminated from the RT analysis. We eliminated outliers according to the procedure used by Dell'Acqua et al. (2007), resulting in the deletion of 0.82% of the tone identification RTs and 0.6% of the picture-naming RTs. Error results in picture naming showed a significant effect of SOA [$F_1(2, 72) = 10.11, p < .001; F_2(2, 94) = 10.13, p < .001$] and no other significant effects ($F_s < 1$). Error results in tone identification showed marginal effects of SOA [$F_1(2, 72) = 2.53, p = .09; F_2(2, 94) = 2.59, p = .09$] and condition [$F_1(1, 36) = 3.10, p = .09; F_2(1, 47) = 3.00, p = .09$] and no other significant effects ($F_s < 1$). We removed 5 participants who failed to follow the task instructions, and so made more than 20% errors in the tone identification task.

SR, semantically related; UR, semantically unrelated

significantly different from each other, as revealed in a series of post-hoc t tests ($ps > .31$). When naming pictures, participants made fewer errors as the SOA increased (1.1%, 0.48%, and 0.31%). Participants also identified tones faster as SOA increased (584, 571, and 559 ms). We found the classic PRP effect, in which Task 2 RTs slowed the more that the two tasks overlapped (i.e., at shorter SOAs; see Fig. 3). This pattern of results is inconsistent with Dell'Acqua et al. (2007), since we did not replicate the decreasing semantic interference effect across increasing SOAs.

Although we used a design almost identical to that of Dell'Acqua et al. (2007), our design varied from theirs in two ways. First, we did not use the Dell'Acqua et al. (2007) picture stimuli, but instead the Snodgrass and Vanderwart (1980) stimulus set. We think it unlikely that the picture stimuli themselves contributed to the presence or absence of the semantic interference effect at SOA 100, given that the Dell'Acqua et al. (2007) picture stimuli are similar to the Snodgrass pictures on a variety of measures (Dell'Acqua, Lotto, & Job, 2000). However, a second difference between the designs was that we did not completely randomize trial order (we controlled for picture name and condition sequences). Van Maanen and van Rijn (2010) found that the interference effect disappeared at SOA 100, depending on trial order. Order effects therefore may have occurred

in Dell'Acqua et al. (2007) but not in the randomization we used in Experiment 1a. Thus, we performed the next experiment (1b) with several goals in mind.

In Experiment 1b, first we completely randomized trial order, to more closely hew to the Dell'Acqua et al. (2007) design. Second, we sought to generalize the Experiment 1a results to a new set of materials. Finally, we replaced SOA 1,000 with an even longer SOA of 1,500 ms, to maximize the size of the semantic interference effect at the later SOA, in an attempt to increase our power to detect an interaction between condition and SOA.³

Experiment 1b

Method

All aspects of Experiment 1b were the same as those of Experiment 1a, except that (1) 31 students participated; (2) we used a new set of materials adapted from other sources (contact authors for our materials); (3) we replaced the 1,000-ms SOA with an SOA of 1,500 ms; and (4) we completely randomized the order of trials, to more strictly

³ We thank Leendert van Maanen for these suggestions.

Fig. 3 Experiment 1a response time (RT) quartile analysis. SOA refers to the time between Stimulus 1 presentation (tone) and Stimulus 2 presentation (picture). Following Dell’Acqua et al. (2007) and others (e.g., Fagot & Pashler, 1992), to demonstrate the classic psychological refractory period effect statistically, we divided the tone identification RTs into quartiles and calculated the mean tone and naming RTs across subjects for trials within each quartile. We analyzed picture-naming RTs with SOA and tone identification RT quartile as independent variables in an ANOVA. There was a significant effect of quartile on picture-naming RTs, such that the majority of the slowest tone-RT trials created the slowest picture-naming trials [$F(3, 107) = 433.05, p < .0001$]. This effect of quartile interacted significantly with SOA, such that at the shortest SOAs the effect of tone identification quartile was largest, whereas this effect disappeared at the longest SOAs [$SOA \times \text{Quartile}: F(6, 201) = 113.03, p < .0001$]. RT1, response time to tone task; RT2, response time to picture task; Q1–Q4, quartiles of RT1 (Q1 = shortest RTs, Q4 = longest RTs)

follow the original Dell’Acqua et al. (2007) experimental design.

Results

The mean RTs, error rates, and error ANOVA statistics for both tone identification (Task 1) and picture naming (Task 2) are displayed in Table 2, along with simple effect statistics. Figure 4 displays the average RTs for both tasks at all SOAs and RT ANOVA statistics. Significant effects are discussed below.

The participants were 31 ms slower to name pictures in the presence of semantically related rather than unrelated distractors, and picture-naming RTs decreased across SOAs. Most importantly, the interference effect was significant at all SOAs, on average 25 ms (95% CI: 2–48 ms), 44 ms (95% CI: 20–67 ms), and 25 ms (95% CI: 2–48 ms) at SOAs 100, 350, and 1,500, respectively (see Fig. 4 and Table 2). Furthermore, the interference effects across SOAs were not significantly different from each other ($ps > .11$). When naming pictures, participants made fewer errors as the SOA increased (2.4%, 1.8%, and 0.98%, respectively, at increasing SOAs). We found the classic PRP effect, in which Task 2 picture naming RTs slowed the more that the two tasks overlapped (at shorter SOAs; see Fig. 5).

Table 2 Mean tone identification and picture-naming response times (RTs, in milliseconds; calculated from participant means, with standard deviations in parentheses) and error rates (as percentage means and

standard errors) for each stimulus onset asynchrony (SOA) and distractor condition (SR or UR to picture)

Conditions	Tone Identification Response		Picture-Naming Response	
	Response Time	Error Rate	Response Time	Error Rate
SOA = 100 ms				
Related	656 (34)	5.4 (0.97)	1,091 (34)	2.4 (0.48)
Unrelated	641 (34)	5.8 (0.98)	1,067 (34)	2.4 (0.48)
Picture naming Δ (SR – UR) 25 ms		$t_1(42) = 2.15, p = .03; t_2(94) = 2.11, p < .001$		
SOA = 350 ms				
Related	631 (34)	6.6 (0.98)	929 (34)	2.3 (0.48)
Unrelated	626 (34)	4.7 (0.97)	885 (34)	1.4 (0.48)
Picture naming Δ (SR – UR) 44 ms		$t_1(42) = 3.79, p < .001; t_2(94) = 3.74, p < .001$		
SOA = 1,500 ms				
Related	635 (34)	4.7 (0.98)	793 (34)	1.1 (0.49)
Unrelated	635 (34)	4.2 (0.98)	768 (34)	0.8 (0.49)
Picture naming Δ (SR – UR) 25 ms		$t_1(42) = 2.16, p = .03; t_2(94) = 1.44, p = .15$		

We report t tests of the semantic interference effect (Δ) at each SOA. The t_1 statistics used Participants as the repeated factor, and the t_2 statistics used Items as the repeated factor. The analyses did not include trials with microphone errors for picture naming (3.9%) or trials on which Task 2 (picture naming) occurred erroneously before Task 1 (tone decision) (3.8%). Trials with either inaccurate tone discrimination (10.9%) or picture naming (3.9%) were eliminated from the RT analysis. We eliminated outliers according to the procedure of Dell’Acqua et al. (2007), resulting in the deletion of 0.7% of the tone identification RTs and 0.5% of the picture-naming RTs. Error results in picture naming showed a significant effect of SOA [$F_1(2, 42) = 5.98, p < .01; F_2(2, 94) = 6.44, p < .01$] and no other significant effects ($ps > .21$). Error results in tone identification showed no significant effects ($ps > .10$). We removed 9 participants who failed to follow the task instructions, and so made more than 20% errors in the tone identification task.

SR, semantically related; UR, semantically unrelated

Fig. 4 Experiment 1b results. SOA refers to the time between Stimulus 1 presentation (tone) and Stimulus 2 presentation (picture). ANOVA statistics include F1 analyses, in which Participants was a random factor, and F2 analyses, in which Items was a random factor. The picture-naming RT results showed significant differences for condition [$F_1(1, 21) = 21.84, p < .001$; $F_2(1, 47) = 17.69, p < .001$] and SOA [$F_1(2, 42) = 673.11, p < .0001$; $F_2(2, 94) = 4.96, p < .0001$], but the Condition $\times$ SOA interaction was not significant [$F_1 < 1$; $F_2(2, 94) = 1.39, p = .25$]. The tone identification RT results showed a marginal effect of SOA [$F_1(2, 42) = 4.61, p = .02$; $F_2(2, 94) = 2.30, p = .10$], and p s were $> .23$ for the main effect of condition and the Condition $\times$ SOA interaction. SR, semantically related distractor; UR, unrelated distractor

Discussion

In two dual-task experiments using picture–word interference in the PRP paradigm, we found semantic interference effects for PWI at both short and long SOAs following tone identification. In line with previous results with the Stroop paradigm (Fagot & Pashler, 1992), this pattern of results

suggests that semantic competition occurs at the point of response selection (e.g., Roelofs, 1992) or later (Mahon et al., 2007), and thus is consistent with models of word production that imply that picture–word semantic interference is a postperceptual effect.

Why did we fail to replicate the Dell’Acqua et al. (2007) results? It is unlikely that our results are due to methodological differences in stimuli or trial order, as Experiments 1a and 1b yielded similar results, even though the stimuli and trial order randomization varied. Also, it is unlikely that participants grouped their responses for the tone and picture tasks before the execution of either task (de Jong, 1993). Following Huestegge and Koch (2009), we empirically tested whether our participants waited to respond to the tone until the picture was presented by checking whether differences between the Response 1 and 2 RTs were constant across SOAs, independent of when Response 1 occurred. In contrast to this prediction, the interresponse interval significantly changed depending on SOA, across all SOAs and in both experiments (p s $< .001$). Thus, the significant interference effect across all SOAs was unlikely to be due to a response grouping strategy on the part of our participants, nor to methodological differences in the materials or trial order.

The differing pattern of results across our lab and others may be due to differing strategic responses to the attentional demands of combining tone detection with picture naming, in terms of ensuring appropriate ordering of responses. As Dell’Acqua et al. (2007, p. 722) acknowledged, the disappearance of the PWI effect at short SOAs might not reflect a perceptual locus of the effect. Meyer and Kieras (1997) and others (Byrne & Anderson, 2001; Schumacher et al., 1999) have argued that when Task 1 response execution is difficult or takes a long time with respect to Task 2, in order to ensure correct task ordering in PRP experiments, participants might strategically “lock” advancement of Task 2 (following response selection) until the Task 1 response execution stage begins. Thus, while waiting for Task 1 execution to begin, response selection/interference resolution for Task 2 takes place and is absorbed in the cognitive slack.

In fact, we have evidence that when Task 1 was difficult for individuals in our study, the interference effect disappeared at SOA 100. When we analyzed the data from participants who made more than 20% errors on Task 1 ($n = 9$; originally excluded from Exp. 1b), we found a marginally significant interaction between interference effect (condition) and SOA ($p = .07$), in which the magnitude of the interference effect was -45 ms at SOA 100 and 18 ms at SOA 1,500. Consistent with this explanation, Ayora et al. (2011) reported an average Task 1 (tone) error rate of 16.5% at SOA 100 and no

Fig. 5 Experiment 1b response time (RT) quartile analysis. SOA refers to the time between Stimulus 1 presentation (tone) and Stimulus 2 presentation (picture). There was a significant effect of quartile on picture-naming RTs [$F(3, 62) = 216.16, p < .0001$], and quartile significantly interacted with SOA [$F(6, 120) = 114.44, p < .0001$]. RT1, response time to tone task; RT2, response time to picture task; Q1–Q4, quartiles of RT1 (Q1 = shortest RTs, Q4 = longest RTs)

significant interference effect. However, it is unclear how Task 1 was more difficult for participants in the Dell'Acqua et al. (2007) experiments, given that their error rates were quite small (3%) and the average tone RTs were within our range (550–650 ms).

In general, combining picture naming and decision tasks may produce variable interference effects. When preparing to name a picture and then deciding whether or not to read a word, the semantic interference effect appears upon immediate naming (Janssen, Schirm, Mahon, & Caramazza, 2008), but also disappears under the same circumstances (Mädebach, Oppermann, Hantsch, Curda, & Jescheniak, 2011; Piai, Roelofs, & Schriefers, 2011). Other reported variable interference effects have been attributed to the processing speed of the distractor words (van Maanen & van Rijn, 2010). Thus, the complexity of dual-task performance may not be captured in standard, response bottleneck accounts of the PRP effect.

Our pattern of results is similar to that seen in the Stroop and PRP paradigms (Fagot & Pashler, 1992), suggesting that Stroop and PWI semantic interference arise from similar processes. This is supported both by similar empirical effects in the two paradigms and by computational models that instantiate the same principles to explain both effects (Cohen et al., 1990; Roelofs, 2003). A more recent computational model (van Maanen, van Rijn, & Borst, 2009) was developed to accommodate the differences between PWI (Dell'Acqua et al., 2007) and Stroop in the PRP paradigm (Fagot & Pashler, 1992). As in the WEAVER++ model (Roelofs, 1992, 2003), van Maanen et al. (2009) implemented semantic interference as arising from competition between representations. However, in the van Maanen et al. (2009) model, the type of representation (and thus the stage of processing) that creates competitive interference is different between the Stroop and PWI paradigms. Van Maanen et al. (2009) suggested that line drawings are more difficult to identify than are color patches, such that the concept associated with the picture's perceptual features is identified more slowly. As a result, the distractor word has time to activate its concept, and competitive selection between activated concepts arises, creating the PWI effect. For the Stroop task, because colors are easier to identify, the color concept is quickly activated, and the word associated with the concept competes for selection with the distractor word, a lexical effect.

The van Maanen et al. (2009) model is hard to reconcile with evidence in the Stroop and PWI paradigms for several reasons. First, it is questionable whether the semantic interference effect in the PWI paradigm occurs before central processing/response selection stages, as the interference effect is variable in dual-task situations, as could be seen here and elsewhere (Mädebach et al., 2011; Piai et al., 2011). Second, the perceptual-locus

interpretation of the null interference effect in dual-task situations is under debate (Piai et al., 2011). Third, the assumption that concepts are competitively selected for is not currently well-supported by the empirical evidence. Competitive selection at the conceptual level during naming is an assumption that would be required in order to motivate why interference in PWI occurs at a perceptual-encoding stage: "When a concept's activation results in a retrieval ratio larger than the [Luce, 1986] threshold, the concept is made available" (van Maanen et al., 2009, p. 991). However, if concepts compete for selection, creating interference at the conceptual level, it is unclear how this model could accommodate the semantic facilitation and interference effects in the PWI paradigm (e.g., Bloem, van den Boogaard, & La Heij, 2004; cf. van Maanen, van Rijn, & Taatgen, 2011) as well as the disappearance of interference when naming is not required (e.g., Levelt, Roelofs, & Meyer, 1999; cf. van Maanen & van Rijn, 2007). Thus, behavioral evidence in word production is not consistent with a conceptual locus of semantic interference effects.

The overall implications of our results are twofold. First, measurement of the semantic interference effect in dual-task situations is variable, possibly due to response ordering factors (Meyer & Kieras, 1997; Piai et al., 2011). Second, the semantic interference effect for PWI in the PRP paradigm patterns like the Stroop effect (Fagot & Pashler, 1992), suggesting that both interference effects, at least as demonstrated in this type of empirical manipulation, are postperceptual effects involving response selection or response execution mechanisms. Whether the semantic interference effect in both paradigms is due to competition during lexical selection (e.g., Roelofs, 2003), to the clearing of an articulatory buffer (e.g., Mahon et al., 2007), or to other mechanisms remains a question for future study.

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