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Mediated phonological–semantic priming in spoken word production: Evidence for cascaded processing from picture–word interference

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Abstract

The cognitive architecture that allows humans to retrieve words from the mental lexicon has been investigated for decades. While there is consensus regarding a two-step architecture involving lexical-conceptual and phonological word-form levels of processing, accounts of how activation spreads between them (e.g., in a serial, cascaded, or interactive fashion) remain contentious. In addition, production models differ with respect to whether selection occurs at lexical or postlexical levels. The purpose of this study was to examine whether mediated phonological–semantic relations (e.g., *drip* is phonologically related to *drill* that is semantically related to *hammer*) influence production in adults as predicted by models implementing cascaded processing and feedback between levels. Two experiments using the picture–word interference (PWI) paradigm were conducted using auditory (Exp. 1) and written (Exp. 2) distractors. We hypothesised that a mediated semantic interference effect would be observable in the former with the involvement of both spoken word production and recognition, and in the latter if lexical representations are shared between written and spoken words in English, as assumed by some production accounts. Furthermore, we hypothesised a mediated semantic interference effect would be inconsistent with a postlexical selection account as the distractors do not constitute a relevant response for the target picture (e.g., *drip*-HAMMER). We observed mediated semantic interference only from auditory distractors, while observing the standard semantic interference effect from both auditory and written distractors. The current findings represent the first chronometric evidence involving spoken word production and recognition in support of cascaded processing during lexical retrieval in adults and present a significant challenge for the postlexical selection account.

Keywords

Speech production; semantic interference; PWI; mediated semantic priming

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Multiple processes contribute to producing the right word associated with a real-world object or idea. In psycholinguistics, this mechanism is referred to as *lexical retrieval*. Most contemporary theories divide lexical retrieval into two different stages: the first step consists of identifying units that combine conceptual, lexical, and syntactic knowledge (also called "lemmas") and the second stage involves the retrieval of the phonological word form (Dell

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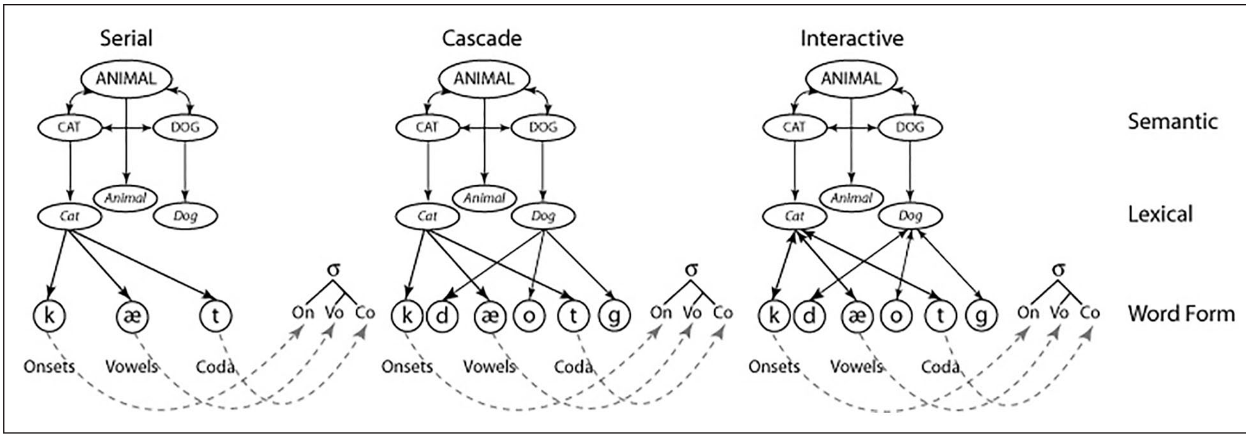

Figure 1. Examples of spreading activation model architectures: serial (Levelt et al., 1999), cascaded (Peterson & Savoy, 1998), and interactive (Dell & Sullivan, 2004).
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& Sullivan, 2004; Levelt, 2001). While this two-step architecture is adopted by the majority of production models, the nature of the information flow between the two stages remains unclear, despite four decades of investigation. Three possible mechanisms of spreading activation between stages have been proposed: serial, cascaded, and interactive (see Figure 1).

The serial model proposed by Levelt and colleagues (1999; Roelofs, 1992) assumes that lexical selection occurs at the first (or lemma) stage involving conceptual and syntactic properties, followed by phonological retrieval and articulation. This model also proposes the phonological code is activated only for the selected lexical concept that will be produced. For example, if the speaker names a picture of a CAT, this lemma is selected among other activated candidates (e.g., other animals, like "dog"), encoded phonologically and produced. The cascade model (Peterson & Savoy, 1998), however, predicts lemma and phonological stages are active simultaneously ("co-active") for a certain period, with phonological encoding commencing before the correct word is selected. In the example above, the cascade model proposes there is a moment in which the phonological forms of "dog" and "cat" are both active, prior to lexical selection. The final model type, proposed initially by Stemberger (1985; see also Berg & Schade, 1992; Dell, 1986; Harley, 1993), hypothesises *interactivity* between the two stages with activation spreading from the lexical-conceptual to phonological levels and vice versa (i.e., feedforward and feedback). All models described above assume activation of a target word and its lexical neighbours. This assumption is supported by errors observed during everyday speech, including semantic paraphasias (e.g., saying "cat" when "dog" was intended; see Harley & MacAndrew, 2001). However, to establish which of the three model architectures is correct, an experimental study is necessary.

Here we focus on one paradigm that has been used chiefly for this purpose, called "picture–word interference" (PWI; Rosinski et al., 1975). While it has been adapted several times since its introduction, the basic structure has remained unchanged: participants name a set of target pictures while a written or auditory distractor is presented at various stimulus onset asynchronies (SOAs) relative to picture presentation, and the reaction times (RTs) corresponding to the start of the articulation of the target words are recorded. The basic finding is that, relative to naming a picture alone, an unrelated distractor word significantly slows target naming latencies (i.e., an interference effect; see Lupker, 1988). A general framework to explain this slower naming in the presence of distractors assumes a production architecture with limited processing capacity, with word distractors processed slightly faster than target pictures, causing a delay in target naming proportional to the time needed to process the distractor.

The PWI effects observed with different distractor types have directly informed the two-step architecture of production models. In an early study, Schriefers et al. (1990) presented auditory distractors that were categorically related ("fox"), phonologically related ("cap"), or unrelated ("phone") to a target picture ("CAT"). The results showed that a categorically related distractor created *semantic interference* (i.e., slowed naming latencies), whereas a phonological distractor induced *facilitation* compared with unrelated distractors. These results have been replicated many times by independent research groups in various languages (e.g., for a recent meta-analysis, see Bürki et al., 2020; also Damian & Martin, 1999; Starreveld & La Heij, 1995, 1996).

Although the PWI evidence for the two-step architecture is robust, the evidence for cascaded versus serial processing is mixed (see Jescheniak & Schriefers, 1998; Peterson & Savoy, 1998). To support a cascaded processing account of production, a demonstration of mediated phonological–semantic priming is needed (see Farrell et al., 2012; Goldrick, 2006; Jescheniak et al., 2017). Using

PWI, this requires a distractor word phonologically related to a category coordinate of the target concept. Using the target "HAMMER" as an example, the distractor "drip" is phonologically related to the category-coordinate "drill" (see O'Seaghdha & Marin, 1997). If multiple lexical concepts and their corresponding phonological word forms are activated as the cascaded account assumes, then "drip" should influence the naming of HAMMER. The expected result would be interference similar to that observed with categorical relations. Note that establishing cascaded processing is a prerequisite for interactive models to allow activation to spread backward (i.e., feedback) from the phonological to lexical-conceptual level (Berg & Schade, 1992; Dell, 1986; Harley, 1993).

Early studies using cross-modal PWI with auditory distractors (Jescheniak et al., 2003; Jescheniak & Schriefers, 1998) failed to observe significant effects for mediated distractor relations, with the authors suggesting the null results were due to insufficient task sensitivity. This explanation was supported by computational simulations with interactive models showing the magnitude of mediated phonological–semantic effects should be smaller compared with direct effects such as semantic interference and phonological facilitation (see Dell & O'Seaghdha, 1991, 1992; Harley, 1993; O'Seaghdha & Marin, 1997). Production researchers therefore turned to other sources of positive evidence to support cascaded-interactive versus serial model architectures. For example, Rapp and Goldrick (2000) were the first to analyse speech error data from brain-damaged patients in relation to model simulations, concluding the strongest locus and extent of cascaded-interactive processing was between lexical and phonological levels of representation. Nevertheless, advocates of serial models were still able to conclude "there is no positive evidence for feedback from chronometric tasks that involve both spoken word production and recognition" (Roelofs, 2003, p. 146). Thus, the question of whether mediated phonological–semantic priming can be demonstrated with PWI has been unresolved for over 30 years.

Alternatively, the use of a distractor SOA of 150 ms *after* the offset of the picture might have been responsible for the earlier null findings in PWI. If during auditory comprehension phonological decoding must take place prior to lexico-semantic retrieval, then this indicates a negative SOA is needed to access the meaning of the distractor prior to that of the target picture (see Damian & Martin, 1999, for discussion of this point). Accordingly, reproducible semantic effects with category distractor–target relations in cross-modal PWI have been reported at early SOAs (e.g., −200, −150, and −100 ms by Damian and Martin (1999); Exps 1 and 3, and −150 ms by Schriefers et al. (1990)). This suggests mediated effects might be observable in cross-modal PWI with a comparable negative SOA.

Indirect evidence for SOA as a critical variable comes from a cross-modal PWI study by Jescheniak and colleagues (2006). They compared PWI performance in primary school children and adults, hypothesising that a relatively prolonged lexical retrieval process in children might allow mediated effects to be detected more readily. In two experiments, the authors used positive (0, +150, and +300 ms; Exp. 1) and early negative SOAs (−600, −450, and −300 ms; Exp. 3). They failed to observe mediated semantic interference in adults but did find it in the children (second graders) at SOAs of +150 and +300 ms, which they interpreted as being consistent with prolonged lexical retrieval. Although the authors dismissed distractor SOA as a potential explanation for the null findings in adults, it is clear that their range of SOAs was both earlier and later than those at which semantic category effects have been reliably reported in cross-modal PWI in adults (Damian & Martin, 1999; Schriefers et al., 1990).

A demonstration of mediated semantic interference would also have implications for proposals for selection mechanisms implemented in production accounts, particularly with respect to semantic effects in PWI. For example, lexical selection-by-competition accounts assume semantic interference results from reciprocal priming (or co-activation) of distractors and categorically related target pictures. This raises activation levels of a cohort of lexical coordinates via a shared category node, inducing competition that delays target selection, for example, computed via Luce's (1959) ratio (see Abdel Rahman & Melinger, 2009; e.g., Levelt et al., 1999; Roelofs, 1992). By contrast, unrelated distractors are not co-activated and so compete less. An alternative noncompetitive, postlexical selection mechanism has also been proposed. According to the response-exclusion hypothesis (REH; Dhooge & Hartsuiker, 2011; Mahon et al., 2007), semantic interference reflects the product of two processes: Semantic overlap between distractors and target pictures facilitates naming latencies via conceptual-lexical priming, but as category membership is assumed to be a response-relevant criterion, a postlexical decision mechanism takes longer to clear the related distractor response from an articulatory output buffer. Thus, this account necessarily predicts facilitation rather than interference with mediated phonological–semantic distractor relations, as the distractor does not satisfy response-relevant criteria, that is, the distractor "drip" while phonologically related to a category-coordinate "drill" does not itself share category membership with the target "HAMMER."

The present study

The aims of this study were to provide the first direct evidence in adults of mediated semantic interference in a chronometric task involving spoken word production and recognition and by doing so, adjudicate between lexical and postlexical accounts. Two PWI experiments will be reported, the first with auditory distractors and the second with written distractors, each using optimal SOAs to detect semantic effects according to the literature. We predicted mediated semantic interference in the first cross-modal experiment, of a relatively smaller magnitude than the interference effect produced by categorical relations (Dell & O'Seaghdha, 1991, 1992; Harley, 1993; O'Seaghdha & Marin, 1997). Similarly, in Experiment 2, we predicted mediated phonological–semantic interference with written distractors, due to the fact that, in English, orthography and phonology are deeply confounded and due to the view that lemmas are shared between written and spoken words (Indefrey, 2011; Indefrey & Levelt, 2004). However, if access to word meaning is not necessarily dependent on written words being converted to their corresponding word forms, as indicated by cognitive neuropsychological evidence and proposed by some production models, then it is possible that a mediated semantic effect might not be observed with written distractors (see Caramazza, 1997; Caramazza & Miceli, 1990; Rapp & Damian, 2018). In addition, we did expect to replicate the standard semantic interference effect with categorical relations with written distractors.

Experiment 1

Method

Participants. Twenty healthy participants (15 females, mean age: 21.15 years, range: 17–45) volunteered from the student body of QUT's School of Psychology and Counselling. All of them were right-handed, English native speakers, and with no history of neurological disorders and with normal (or corrected) vision. The students received 2 hr/credits towards their course of study as compensation for participation.

Design. The independent variables (IVs) were the type of distractor (Category Relationship, Mediated Phonological–Semantic relationship) each with two levels (Related and Unrelated). The dependent variable was the RT of speech onset.

Apparatus and stimuli. All materials and data are publicly available via the Open Science Framework at https://osf.io/65f7w/. The target picture stimuli comprised 36 coloured drawings of real-world, common objects with four exemplars from each of nine categories. The majority ($n=30$) were selected from the MultiPic normative database (Duñabeitia et al., 2018) and had high name agreement, whereas the remainder were sourced from the internet. Each target picture was presented 4 times during the experiment, each time with a different distractor word. The categorically related distractor words were target words on other trials, that is, response set members. The distractor words in the related conditions were paired with different pictures to create unrelated distractors. We deliberately minimised confounding neighbours (i.e., words in the same category as the target picture) when constructing the mediated phonological-related distractors. Distractors across categorically related and mediated phonological–semantic-related conditions were matched closely on a range of lexical properties using the English Lexicon Project normative database (Balota et al., 2007), including log frequency (SUBTLEX; Warriner et al., 2013), the number of letters, phonemes, and syllables, concreteness, age of acquisition (AoA; Kuperman et al., 2012), semantic diversity (Hoffman et al., 2013), orthographic (Yarkoni et al., 2008), and phonological (Suárez et al., 2011). Levenshtein distances (OLD20 and PLD20), spelling-to-sound (feedforward), and sound-to-spelling (feedback) consistency measures for first syllable and composite (for multisyllabic words) onsets (Chee et al., 2020; see Table 1). The auditory distractors were recorded by a female native English speaker in an anechoic chamber, and edited and normalised using Audacity (Audacity Team, 2019) and the DC offset removed. The words were matched across distractor conditions on all lexical variables (all $ps > .05$), except AoA, $t(70)=4.87$, $p < .001$, and word length, $t(70)=2.09$, $p=.04$. The distractor words we employed were all acquired in early childhood (i.e., within the first 10 years of age) and word length differed on average by less than a single letter across conditions.[1]

We also calculated the strength of the semantic relationships between each distractor type and the target pictures via latent semantic analysis (Wolfe & Goldman, 2003; see Table 2). The mean semantic relationship between targets and categorically related distractors was significantly stronger than those between the targets and mediated phonological–semantic, $t(35)=9.66$, $p < .001$, and unrelated, $t(35)=7.61$, $p=.001$, distractors. Furthermore, the strength of the semantic relationship between the targets and mediated phonological–semantic distractors did not differ significantly with those between the unrelated distractors and targets (all $ps > .05$).

The stimuli were displayed via a 15″ laptop screen and headphones using MATLAB (2017; The Mathworks Inc., 2017) with the Cogent 2000 toolbox extension (http://www.vislab.ucl.ac.uk/cogent_2000.php). Vocal responses were recorded using a noise cancelling microphone and onset RTs extracted automatically from the digital audio recording using Chronset (Roux et al., 2017).

Procedure. Before the experiment, participants were familiarised with the target pictures per the typical PWI procedure (see Gauvin et al., 2018). Each picture was presented 3 times in random order with the instruction that they were to be named out loud. The first presentation involved the written name of the corresponding picture printed below it, whereas the subsequent two presentations entailed only the picture. Erroneous responses were corrected by the experimenter.

A PWI paradigm was next employed: Participants were instructed to name aloud the target pictures as quickly and accurately as possible while ignoring the distractor. The

Table 1. Lexical properties of the distractors employed in the experiment.

Lexical property	Distractor type			
	Category		Phonological–Semantic	
	M	*SD*	*M*	*SD*
Letters	4.5	1.1	5.0	1.1
Phonemes	3.6	0.8	3.9	1.0
Syllables	1.2	0.4	1.3	0.5
Frequency	3.2	0.6	2.8	0.7
Concreteness	4.9	0.2	4.5	0.7
Age of acquisition	4.4	1.3	6.5	2.3
Semantic diversity	1.6	0.2	1.6	0.2
OLD20	1.5	0.4	1.7	0.4
PLD20	1.3	0.4	1.4	0.4
Feedforward consistency (Syllable 1 onset)	0.96	0.05	0.96	0.05
Feedforward consistency (composite onset)	0.77	0.3	0.81	0.28
Feedback consistency (Syllable 1 onset)	0.95	0.15	0.95	0.15
Feedback consistency (composite onset)	0.65	0.3	0.64	0.3
Auditory duration (ms)	546	90	583	93

Note. M: mean; *SD*: standard deviation. Refer to text for normative data sources.

Table 2. Strength of semantic relationships between distractor types and target pictures according to LSA.

Categorically related	Unrelated	Phonological–Semantic	Unrelated
0.32 (0.17)	0.08 (0.08)	0.05 (0.06)	0.06 (0.06)

Note. Values are means with standard deviations (*SDs*) in parentheses.

target picture was presented at the centre of the screen for 750 ms on a white background. The auditory distractor was presented before the picture, with an optimal −150 ms SOA for detecting the semantic interference effect according to previous PWI studies using auditory distractors (Damian & Martin, 1999; Schriefers et al., 1990; cf. Jescheniak et al., 2003, 2006; Jescheniak & Schriefers, 1998). After each picture 1,750 ms of blank screen was presented followed by a fixation cross for 500 ms. The response latencies were recorded starting from the onset of the picture.

Each subject was presented with each picture 4 times, each time with a different distractor type. The series of trials were pseudorandomised across subjects using Mix (van Casteren & Davis, 2006). Within each series, the randomisation was constrained such that the same target picture would not appear within five trials and each condition would not appear more than twice consecutively. The total number of trials was 144. The total duration of the experiment was ~25 min.

Table 3. Mean naming latencies (in ms) as a function of distractor type.

Distractor type	*M*	*SD*
Categorically related	759.73	99.05
Unrelated	735.56	97.17
Semantic interference	24.17	
Mediated phonological–semantic	766.17	96.92
Unrelated	750.16	90.64
Semantic interference	16.01	

Note. Semantic interference = Related − Unrelated. *SD* = standard deviation.

Results

Trials involving speech errors or empty audio files were removed (67 trials, 2.32% of the data). Responses that were 3 *SD* above and below the subject mean or below 250 ms were removed from the analysis (following Damian & Martin, 1999) using R (R Core Team, 2018) and the package "trimr" (Grange, 2015; 57 trials removed, 1.97% of the data). Table 3 summarises the mean RT for each condition and shows longer naming latencies for mediated phonological–semantic and categorically related distractors when compared with their matched unrelated counterparts.

A linear mixed effects (LME) analysis was carried out using the lme4 (v. 1.1-23) package (Bates et al., 2015) within R (R Core Team, 2018) using the "bobyqa" optimiser and with factor levels sum-coded. The model included fixed effects of distractor type (Categorical = −0.5, Mediated Phonological–Semantic = 0.5), distractor relatedness (Unrelated = −0.5, Related = 0.5), and their interaction, as well as (initially) a maximal random effects structure, with random intercepts and all within-factor random slopes for participants, pictures, and distractors, as well as correlations between random slopes. As the maximal model did not converge, it was refit with correlations between random slopes removed. As this model did not converge either, all random slopes accounting for less than 1% of the variance of their respective random factors were removed (Bates et al., 2015; Matuschek et al., 2017), which facilitated convergence without changing any *t* value by more than .01. The final reduced model included all random intercepts and a random slope of distractor relatedness by participant. Visual inspection of residuals showed no breach of normality.

The model showed a nonsignificant effect of distractor type, providing no evidence that the two groups of distractor words slowed picture naming to a different extent, $B=10.72$, $SE=9.28$, $t(56.11)=1.16$, $p=.252$,; a significant effect of distractor relatedness, indicating slower RTs for related distractors, $B=20.34$, $SE=5.30$, $t(18.78)=3.84$, $p=.001$,; and a nonsignificant interaction between distractor type and distractor relatedness, providing no evidence that categorical interference and mediated phonological–semantic interference differed in magnitude, $B=-7.49$, $SE=9.44$, $t(2{,}623.55)=-0.79$, $p=.428$. Two a priori contrasts[2] were computed using the emmeans package (Lenth, 2016) with degrees of freedom computed via the Satterthwaite approximation, revealing a significant difference in RT for mediated phonological–semantic versus unrelated distractors, $t(61.0)=2.33$, $p=.023$, with an estimated difference of 16.6 ms ± 7.12 (*SE*), and a significant difference in RT between categorically related versus unrelated distractors, $t(59.4)=3.41$, $p=.001$, with an estimate difference of 24.1 ms ± 7.07 (*SE*).

A one-tailed, paired sample *t* test was carried out using JASP (v0.11.1; JASP Team, 2019) comparing the magnitudes of the semantic interference effects (i.e., Related − Unrelated) for the two distractor types to test the a priori prediction of interactive activation models that mediated interference would be relatively smaller in magnitude. The ~8 ms difference in magnitudes (categorical > mediated) was not statistically significant, $t(19)=1.18$, $p=.13$, one-tailed. To test confidence in the nonsignificant result of this comparison, a Bayesian one-tailed paired sample *t* test was carried out using JASP. The analysis showed only anecdotal evidence in favour of the null ($BF_{+0}=0.74$, error = ~0.00%).

Discussion

The significant results of Experiment 1 can be summarised as follows: First, we successfully replicated the cross-modal semantic interference effect with categorical distractors reported by Damian and Martin (1999) and Schriefers and colleagues (1990) using a comparable negative SOA. Second, we confirmed the existence of a significant mediated phonological–semantic interference effect at the same SOA in the same speakers. This experiment provides the first PWI evidence, elusive until now in adults, for cascaded processing in spoken word production in adults (cf. Roelofs, 2003). Although the magnitudes of the respective interference effects did not differ significantly, the Bayesian analysis of our data did not provide strong support for the null result.

Experiment 2 was conducted with written distractors to test the hypothesis that mediated phonological–semantic interference is dependent on the involvement of both spoken word production and recognition.

Experiment 2

Method

Participants. Twenty healthy participants (10 females, mean age: 24.6 years, range: 17–45) were selected from the student body of QUT School of Psychology and Counselling through the Psychology Research Management System (SONA). Identical exclusion criteria and compensation were applied as per Experiment 1.

Design. Same as Experiment 1.

Apparatus and stimuli. The stimuli were the same as Experiment 1. The auditory distractors were substituted with written words, and the position of the written distractor (above or below the picture) was randomised across trials. Distractors appeared in Arial font, size 50, in red print, and in capital letters. Stimuli were presented using Cogent 2000 and MATLAB (The Mathworks Inc., 2017) on a 15″ screen. Vocal responses were recorded using a noise cancelling microphone.

Procedure. The procedure followed that of Experiment 1. The SOA for this experiment was set to 0, so that target picture and distractor were presented simultaneously. This SOA has been reported to be optimal for detecting the semantic interference effect according to previous PWI studies using written distractors (Damian & Martin, 1999; Starreveld & La Heij, 1995).

Results

Trials containing errors or empty audio files were removed (108 trials, 4.74% of the data). RT outliers were excluded using the same criteria as Experiment 1 (47 trials removed, 1.63% of the data). Table 4 summarises the mean RT for each condition.

An LME analysis identical to Experiment 1 was conducted. The final reduced model included random intercepts for participant and pictures, and a random slope of distractor type by participant. (Relative to the nonconverging model with maximal random slopes but no correlations

Table 4. Mean naming latencies (in ms) as a function of distractor type.

Distractor type	*M*	*SD*
Categorically related	665.32	91.26
Unrelated	647.51	87.45
Semantic interference	17.81	
Mediated phonological–semantic	645.62	92.69
Unrelated	653.78	94.15
Semantic interference	–8.17	

Note. Semantic interference = Related − Unrelated. *SD* = standard deviation.

between them, no t value changed by more than .01.) Visual inspection of residuals showed no breach of normality.

The model showed a nonsignificant effect of distractor type, providing no evidence that the two groups of distractor words slowed picture naming to a different extent, $B = -6.89$, $SE = 5.38$, $t(18.97) = -1.28$, $p = .216$; a nonsignificant effect of distractor relatedness, providing no evidence of slower RTs for related distractors overall, $B = 6.01$, $SE = 4.50$, $t(2{,}649.75) = 1.33$, $p = .182$; and a significant interaction between distractor type and distractor relatedness, $B = -24.97$, $t(2{,}648.96) = -2.77$, $p = .006$. Two a priori planned contrasts were performed. The contrast between categorically related and unrelated distractors revealed a significant difference in RT, $t(2{,}650) = 2.89$, $p = .004$, with an estimated difference of 18.49 ms ± 6.39 (SE). No significant difference in RT was observed between mediated phonological–semantic related and unrelated distractors, $t(2{,}649) = -1.02$, $p = .307$, with an estimated difference of −6.48 ms ± 6.34 (SE). To test the confidence in the nonsignificant result of this second comparison, a Bayesian paired sample t test was carried out using JASP (JASP Team, 2019). The analysis showed moderate to strong evidence in favour of the null ($BF_{+0} = 0.14$, error = ~0.001%).

A final model was created to test for an interaction between distractor modality and the semantic effects across the data from Experiments 1 and 2, using an identical approach. The resulting reduced model consisted of fixed effects of distractor modality (auditory = −0.5, written = 0.5), distractor type, distractor relatedness, and their interactions; random intercepts for participants, pictures, and distractors; and random slopes of distractor modality (for both pictures and items) and distractor relatedness (for pictures). The model revealed a significant main effect of distractor modality, $B = -99.80$, $SE = 29.55$, $t(39.97) = -3.38$, $p = .001$, and a significant interaction between distractor modality and relatedness, $B = -14.35$, $SE = 6.54$, $t(5{,}268.06) = -2.20$, $p = .028$, but no other interactions involving distractor modality (all ts < 1.6, all ps > .11). Two a priori planned contrasts were performed to test for cross-modality differences between semantic interference and mediated phonological–semantic interference. The result showed a significant cross-modality effect (auditory vs. written) for mediated semantic interference, $t(5{,}267) = 2.48$, $p = .013$, with an estimated difference of −11.47 ms ± 4.62 (SE), but not for the conventional semantic interference effect, $t(5{,}267) = 0.62$, $p = .533$, −2.89 ms ± 4.62 (SE).

Discussion

The results of Experiment 2 with written distractors can be summarised as follows: we observed a significant semantic interference effect, but no evidence of a mediated semantic effect. The Bayesian analysis supports the latter conclusion by showing that the data for the mediated phonological–semantic condition are more likely to reflect the hypothesis of no differences between the conditions. The combined analysis of the two experiments showed a significant distractor modality effect for mediated semantic interference but not for the conventional semantic interference effect, indicating that the observation of mediated phonological semantic interference is contingent on spoken but not written word recognition (although the lack of a three-way interaction means, we cannot conclude that the effect of modality significantly differs between distractor types).

General discussion

Despite multiple efforts to demonstrate mediated semantic-phonological effects using chronometric tasks that involve both spoken word production and recognition, the evidence has been mixed at best (e.g., Jescheniak et al., 2003; Jescheniak & Schriefers, 1998; Roelofs, 2003). Experiment 1 provides the first unequivocal demonstration of a mediated phonological–semantic effect during PWI in adults. While both experiments showed clear semantic interference effects with categorically related distractors, mediated interference was only observed with auditory (Experiment 1) but not written distractors (Experiment 2), confirming the importance of distractor modality for eliciting the latter. Together, these results indicate that in a chronometric task requiring spoken word production, spoken word recognition is required to demonstrate mediated semantic interference. Such interference is predicted by production models that allow for some type of cascading activation between lexical-conceptual and word-form levels. In contrast, mediated semantic interference is difficult to reconcile with a postlexical account of semantic interference.

The findings from our experiments are generally in line with the predictions of cascaded models that allow for the simultaneous activation of multiple lexical-conceptual and word-form representations during production (e.g., Jescheniak & Schriefers, 1998; Peterson & Savoy, 1998). This is essentially the same mechanism but operating in the opposite direction to the one proposed for comprehension (e.g., Pickering & Garrod, 2013). Our choice of SOA was the one for which categorical semantic interference effects had been reliably demonstrated in cross-modal

PWI (Damian & Martin, 1999; Schriefers et al., 1990), but previous studies of mediated interference instead opted for SOAs that were either earlier or later (Jescheniak et al., 2003, 2006). Jescheniak and colleagues (2006) observed mediated semantic interference in second-grade primary school children with auditory distractors in PWI using longer SOAs of +150 and +300 ms but were unable to observe the effect in fourth graders or adults at the same SOAs. They suggested mediated effects might be observable in less skilled readers such as second graders, who rely more on prolonged phonological recoding during lexical retrieval. However, the finding of a significant mediated semantic effect of comparable magnitude to the categorical semantic interference effect is somewhat at odds with the predictions from earlier computational simulations with interactive models of speech production (see Dell & O'Seaghdha, 1991, 1992; Harley, 1993; O'Seaghdha & Marin, 1997). Although we were unable to detect a significant difference between the magnitudes of the respective interference effects as predicted by these models, we acknowledge the numerical difference was in the anticipated direction (i.e., a trend to a slightly smaller mediated effect) and the Bayes analysis of our data did not provide strong support for this null result.

The failure to observe a mediated interference effect with written distractors in our adult participants, if a "true" null finding, places some constraints on the nature of activation spreading between lexical-conceptual and word-form levels. Before offering interpretations, it is worth considering whether this result might be due to our choice of SOA. We opted for an SOA of 0 ms as the interference effect observed for categorical relations with written distractors is reported reliably in a small temporal window around target picture presentation (−150 to 150 ms) and is maximal at 0 ms (Damian & Martin, 1999; Glaser & Düngelhoff, 1984; Starreveld & La Heij, 1995). If lexical retrieval operates at high speed, then it is reasonable to assume activation of a competitor's word form should occur relatively quickly. Certainly, the results from Experiment 1 taken together with those of prior studies using auditory distractors indicate mediated priming is more likely to be observed at the same SOA at which categorical semantic interference is maximal, and unlikely to be observed either 150 ms before or after the picture onset (e.g., Jescheniak et al., 2006). Nonetheless, we acknowledge that the use of an earlier or later SOA might reveal a positive result, a possibility we leave for future research.

If we assume the result of Experiment 2 to be a "true" null finding for mediated priming with written distractors, then this appears inconsistent with the assumption that lemmas are shared between written and spoken words in serial models (Indefrey, 2011; Indefrey & Levelt, 2004). Instead, it might indicate a written word is not necessarily converted to its full phonological form (or lexeme) to access its meaning (i.e., phonological recoding), a conclusion supported by neuropsychological evidence in adults (Rapp & Damian, 2018; see also Caramazza, 1997; Caramazza & Miceli, 1990). However, this result could be accommodated by segmental models of speech production (see Dell et al., 1997; Rapp & Goldrick, 2000), in which the encoding and decoding of written words occur not at the lexical but at the sublexical (phoneme) level. For example, if the written distractor "drip" is presented with the target "HAMMER," the sublexical CV component "ha" is first activated and may only partially activate the lexical-level competitor "drill" via the overlapping sublexical component. This relatively weaker activation compared with auditory presentation might be insufficient to elicit a significant lexical-level mediated priming effect.

The design of our PWI experiments also differed from previous studies in terms of the inclusion of categorically related distractor words. In their experiments, Jescheniak and colleagues (2006) included auditory distractors that were phonologically related to category coordinates of the target pictures but omitted categorically related distractors because they wanted to prevent participants from becoming aware of the mediated relations by being exposed to the underlying categorical relations (see their Footnote 1). An explanation for the results of our Experiment 1 based on awareness seems unlikely, however, as we did not observe an effect with written distractors using an identical design in Experiment 2 despite strong orthography and phonology mapping in English.

Interestingly, Abdel Rahman and Melinger (2008; Experiments 3 and 4) were able to demonstrate mediated semantic interference with a modified PWI paradigm using multiple written distractor words provided that the categorically related distractor was part of the response set, that is, it was a target utterance on other trials. The present experimental design also employed response set members for categorically related distractors. Competitive lexical selection models such as WEAVER++ assume response set membership increases co-activation of targets and distractors via reciprocal priming and repetition, producing greater competition (e.g., Piai et al., 2012; Roelofs, 1992). When categorical distractors are not part of the response set, semantic interference is assumed to be weaker. This might suggest that for mediated semantic interference to manifest, links with specific semantic competitors need to be strongly co-activated via response set membership, as in the present design. A counterargument to this perspective is that two PWI studies directly manipulated response set membership between and within-participants using written distractors (Caramazza & Costa, 2000; Gauvin et al., 2020), and neither observed a significant change in the magnitude of the conventional semantic interference effect. However, as Bürki et al. (2020) have argued, absence of evidence is not necessarily evidence of absence, so we acknowledge the possibility that our use of response set members for our categorically related distractors might have strengthened co-activation of related word-form representations enabling mediated semantic interference to manifest with spoken distractors.

The mediated interference effect we observed in Experiment 1 also has implications for the REH account of semantic interference in PWI (Dhooge & Hartsuiker, 2011; Mahon et al., 2007). While category membership as a response-relevant criterion might account for postlexical slowing of selection with categorically related distractors, it is unlikely to apply to distractors phonologically related to a semantic competitor due to the fact that they do not share a category with the target. An increase in lexical co-activation with mediated phonological–semantic relations should therefore have resulted in facilitation according to this account. To accommodate the present findings, a post hoc explanation for the response-relevance of mediated relations is required. This explanation would also need to explain why the effect is observed with auditory but not written distractors, particularly when one of the principal assumptions of the REH account is that printed words have privileged access to the articulators (Mahon et al., 2007).

In conclusion, the present findings demonstrate that mediated phonological–semantic interference is observable in a conventional PWI paradigm. This is the first evidence in adults for this phenomenon using a chronometric task involving both spoken word production and recognition. Our findings from both experiments may be interpreted as supporting production accounts that implement cascaded processing and segmental encoding/decoding mechanisms (e.g., Dell et al., 1997; Goldrick, 2006; Rapp & Goldrick, 2000). However, they are difficult to reconcile with the postlexical account of semantic interference (Mahon et al., 2007).

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Supplementary material

The supplementary material is available at qjep.sagepub.com.

Data accessibility statement

The data and materials for all experiments are available at https://osf.io/65f7w/.

Notes

1. Note that age of acquisition (AoA) distractor effects are only observable for late versus early acquired words in picture–word interference (PWI), and there is no evidence for distractor word length modulating semantic interference in PWI (see the meta-analysis by Bürki et al. (2020)).
2. We performed planned contrasts as they are typically conducted whether or not the overall F test is significant; at least this is the convention according to introductory experimental design and statistics textbooks (e.g., Hahs-Vaughn & Lomax, 2012; Keppel, 1991; Kirk, 2014; Levin et al., 1987).

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