Semantic interference is not modality specific:
Evidence from sound naming with distractor pictures

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Abstract

In three experiments participants named environmental sounds (e.g., the bleating of a sheep by producing the word “sheep”) in the presence of distractor pictures. In Experiment 1 we observed faster responses in sound naming with congruent pictures (e.g., sheep; congruency facilitation) and slower responses with semantically related pictures (e.g., donkey; semantic interference), each compared to unrelated pictures (e.g., violin). In Experiments 2 and 3, we replicated these effects and used a psychological refractory period approach (combining an arrow decision or letter rotation task as task 1 with sound naming as task 2) to investigate the locus of the effects. Congruency facilitation was underadditive with dual -task interference suggesting that it arises, in part, during pre-central processing stages in sound naming (i.e., sound identification). In contrast, semantic interference was additive with dual -task interference suggesting that it arises during central (or post-central) processing stages in sound naming (i.e., response selection or later processes). These results demonstrate the feasibility of sound naming tasks for chronometric investigations of word production. Furthermore, they highlight that semantic interference is not restricted to the use of target pictures and distractor words but can be observed with quite different target-distractor configurations. The experiments support the view that congruency facilitation and semantic interference reflect some general cognitive mechanism involved in word production. These results are discussed in the context of the debate about semantic-lexical selection mechanisms in word production.

Keywords: word production; semantic processing; environmental sounds; cross-modal interaction; dual task

Introduction

Familiar objects that we perceive in our environment, say a dog, readily activate specific semantic representations that make available different pieces of knowledge, for example that it can move quickly, sometimes bites, and is named “dog” (e.g., Lambon Ralph, 2014). The same is true when we perceive environmental sounds, for example a dog’s barking (see e.g., Chen & Spence, 2018, of a recent integrative model of picture, sound, and word processing). Studying object or picture processing has a long standing tradition in cognitive psychology (e.g., Cattell, 1886; Glaser, 1992; Humphreys, Riddoch, & Quinlan, 1988; Martin, Wiggs, Ungeleider, & Haxby, 1996; Theios & Amrhein, 1989; Thorpe, Fize, & Marlot, 1996) while environmental sound processing has been investigated far less extensively (see Hocking, Dzafic, Kazovsky, & Copland, 2013; Uddin, Heald, van Hedger, Klos, & Nusbaum, 2018). Because pictures are reliably mapped onto lexical representations, picture naming has become a most prominent tool in speech production research and data obtained with variants of that task have been critical in devising detailed processing models of word production. However, any comprehensive model of word production should not rely solely on evidence from one task and complementary evidence from other tasks is needed to evaluate the task-specificity of critical findings. In the present article, we present a series of experiments testing for semantic context effects in a sound naming task. Specifically, we explored whether an effect regularly found in picture naming and which is central to theory building, namely semantic interference from a distractor stimulus, generalizes to sound naming.

Semantic context effects in picture naming have informed nearly all contemporary models of spoken word production (e.g., Abdel Rahman & Melinger, 2009, 2019; Bloem & La Heij, 2003; Levelt, Roelofs, & Meyer, 1999; Roelofs, 2018).

One important finding is the demonstration of semantic interference in the picture-word interference task (e.g., Glaser & Dünghoff, 1984; Schriefers, Meyer, & Levelt, 1990). Picture naming takes longer when the picture is presented with a distractor word which denotes a category coordinate of the picture (e.g., picture: sheep, distractor word: donkey) compared to an unrelated distractor word (e.g., distractor word: violin). The interpretation of this effect has fueled a vivid and productive debate regarding the question of whether lexical selection is a competitive or a non-competitive process (e.g., Abdel Rahman & Melinger, 2009; Finkbeiner & Caramazza, 2006; La Heij, Kuipers, & Starreveld, 2006; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007; Mahon & Caramazza, 2009; Mulatti & Coltheart, 2012; Navarrete & Mahon, 2013; Roelofs & Piai, 2013; for a review see Spalek, Damian, & Bölte, 2013). One critical question in this debate is whether semantic interference reflects a general cognitive mechanism involved in conceptually driven word production (e.g., Levelt et al., 1999; Roelofs, 2018) or whether it is task specific and confined to task configurations using distractor words (as is the case in the picture-word interference task; see Finkbeiner & Caramazza, 2006, Mahon et al., 2007).

A crucial assumption of competitive selection is that the speed of target selection depends on both target and competitor activation (e.g., Roelofs, 1992). Consequently, semantic priming between a semantically related target and distractor stimulus has two opposing consequences: target priming (i.e., activation of the target increasing due to semantic priming by the distractor) and distractor priming (i.e., activation of the distractor increasing due to semantic priming by the target). In the competitive framework, semantic interference is assumed to reflect that distractor priming, which increases competition, outweighs target priming, whereas semantic facilitation, which can also be observed under certain task configurations, is assumed

to reflect that target priming outweighs distractor priming (see Abdel Rahman & Melinger, 2009; Hantsch, Jescheniak, & Schriefers, 2009).

According to the non-competitive selection view, the speed of lexical selection depends only on target activation (e.g., Mahon et al., 2007). Therefore, semantic facilitation effects can be explained simply by target priming. However, semantic interference effects have to be explained differently if competitor activation (distractor priming) is irrelevant for the speed of lexical selection. Such non-competitive explanation is given by the response-exclusion hypothesis (Finkbeiner & Caramazza, 2006; Mahon et al., 2007). It assumes semantic interference from distractor words to arise because distractor words are prepared automatically and quickly as an articulatory response which then needs to be excluded from production before the target picture name can be produced. The control processes involved in this exclusion have been linked to general monitoring mechanisms in word production (Dhooge & Hartsuiker, 2010) and are proposed to be sensitive to semantic similarity between the distractor response and the target response with slower exclusion of semantically related (response relevant) distractor words (Finkbeiner & Caramazza, 2006; Mahon et al., 2007). A core assumption of this non-competitive account is that semantic interference is restricted to distractor words. A number of studies using distractor pictures instead of distractor words (picture-picture interference task) have produced mixed results, with some studies showing semantic facilitation or no effect (e.g., La Heij, Heikoop, Akerboom, & Bloem, 2003; Damian & Bowers, 2003; Geng, Kirchgessner, & Schnur, 2013) and others showing semantic interference (e.g., Jescheniak, Matushanskaya, Mädebach, & Müller, 2014; Matushanskaya, Mädebach, Müller, & Jescheniak, 2016; see also Aristei, Zwitterlood, & Abdel Rahman, 2012). A recent comprehensive series of picture-picture interference experiments from our lab, using different kinds of materials, stimulus configurations,

and task cues, however, has showed semantic interference from distractor pictures quite consistently (Mädebach, Wöhner, & Jescheniak, 2018). Moreover, semantic interference in picture naming has also recently been shown with distractor sounds (Mädebach, Wöhner, Kieseler, & Jescheniak, 2017; Mädebach, Kieseler, & Jescheniak, 2018). These observations are at odds with the idea that semantic interference is confined to picture naming with distractor words.

In the present study we moved another step forward and tested for semantic context effects in a novel task configuration that differs from the classical picture-word interference task with respect to both target stimuli and distractor stimuli. Instead of pictures, we used environmental sounds as targets. Instead of words, we used pictures as distractors. Our main goals were to test (a) whether environmental sounds can be utilized in chronometric investigations of word production processes at all and (b) whether semantic interference is also obtained in sound naming with distractor pictures. The outcome of our experiments shall provide further information with regard to the question of whether semantic context effects reflect some general cognitive mechanism of conceptually driven word production rather than some mechanism that is confined to a restricted set of task configurations. Moreover, they may help to shed further light on the processes involved in sound naming itself, because to date little is known about how environmental sounds are processed and named (Hocking et al., 2013; Uddin et al., 2018). The majority of studies on cross-modal semantic interactions between environmental sounds and pictures has focused on the effects of environmental sounds when processing target pictures (Chen & Spence, 2010, 2011, 2018; Iordanescu, Guzman-Martinez, Grabowecky, & Suzuki 2008; Iordanescu, Grabowecky, Franconeri, Theeuwes, & Suzuki, 2010; Kvasova, Garcia-Vernet, & Soto-Faraco, 2019; Mädebach et al., 2017). The present experiments complement and extend these previous studies by investigating whether

cross-modal semantic interactions between pictures and sounds are affecting sound processing in a similar way as picture processing (cf. Schneider, Engel, & Debener, 2008, Yuval-Greenberg & Deouell, 2009).

Overview over the present study

In our experiments, participants named environmental sounds (e.g., the bleating of a sheep by producing the name of the entity associated with it – “sheep”) while ignoring distractor pictures (sound-picture interference task). We implemented three distractor conditions in the experiments: a congruent distractor condition (e.g., distractor picture sheep), a semantic distractor condition (e.g. distractor picture donkey), and an unrelated distractor condition (e.g., distractor picture violin).

Like the naming of pictures, the naming of environmental sounds can be assumed to be conceptually mediated. A recent model of cross-modal interactions of pictures, sounds and words (Chen & Spence, 2018) proposed that both sounds and pictures follow modality specific coarse-to-fine processing pathways when accessing the semantic system. Access to the lexical system is then mediated by shared amodal or multisensory semantic representations. These amodal (or multisensory) semantic representations correspond roughly to the conceptual representations providing input into the lexical system in word production models (see for instance Belke, 2013; Levelt et al., 1999, Vigliocco, Vinson, Lewis, & Garrett, 2004).

Therefore, if semantic context effects in picture naming reflect general (amodal) semantic-lexical selection processes, the same effects should also be obtained in sound naming. Specifically, we would expect facilitation in the congruent compared to the unrelated condition and interference in the semantic compared to the unrelated condition as this would parallel the corresponding effects observed in picture naming

studies with distractor words, distractor sounds, and distractor pictures (Glaser & Döngelhoff, 1984; Mädebach et al., 2017; Mädebach, Wöhner, & Jescheniak, 2018).

We report three experiments. Experiment 1 tested for congruency facilitation and semantic interference from distractor pictures in sound naming (sound-picture interference task). Experiments 2 and 3 sought (a) to replicate the distractor effects from Experiment 1 and (b) to provide information about their locus. These experiments used a dual task following the psychological refractory period (PRP) logic (e.g., Pashler, 1994; Telford, 1931) and combined the sound-picture interference task from Experiment 1 with a visual discrimination task. The discrimination task served as task 1 (T1) and the sound-picture interference task as task 2 (T2). Experiment 2 used an arrow decision task as T1 and Experiment 3 a letter rotation task. Participants were asked to first perform the discrimination task by giving a button press response before naming the sound. The relative onsets of T1 and T2 stimuli (task SOA) was varied in two steps – short task SOA (0 ms in Experiments 2 and 3) and long task SOA (500 ms in Experiment 2, 1,500 ms in Experiment 3). We expected standard dual-task interference, that is, longer response latencies in T2 (sound naming) with the short task SOA as compared to the long task SOA. Of critical interest was how this dual-task interference would affect distractor effects in T2. Following the assumption of a central processing bottleneck, dual-task interference reflects that response selection (requiring central processing capacity) of T2 cannot proceed until response selection of T1 is completed. This delay in central processes of T2 results in a cognitive slack. This cognitive slack – if sufficiently large – can absorb differences in processing durations of pre-central processes in T2 to some extent. Consequently, distractor effects which arise during pre-central processing stages of T2 should decrease at a short task SOA when compared to a long task SOA, whereas distractor effects which arise during central (i.e., response

selection) or later processing stages of T2 should be unaffected. Specifically, if congruency facilitation or semantic interference from distractor pictures in sound naming arise (in part) during early pre-central processing (i.e., perceptual and conceptual processing required for sound identification), the respective effect should be reduced at the short task SOA. In contrast, if congruency facilitation or semantic interference arise during later central processing (i.e., selection of the naming response), the respective effect should be independent of task SOA.

Experiment 1

In Experiment 1, participants named environmental sounds while ignoring distractor pictures. Distractor pictures were either presented slightly before (SOA - 200 ms) or simultaneously with the target sounds (SOA 0 ms) to increase the chance of tapping into a time window suitable to observe distractor effects. We predicted interference from semantically related distractor pictures and facilitation from congruent distractor pictures when compared to unrelated distractor pictures.

We suspected that participants might adapt to the task by withdrawing attention from the computer screen (or even closing their eyes) to avoid distraction while performing the (sound naming) task. Evidently, in this case, no effects from distractor pictures could be expected. In order to ensure that participants indeed processed the distractor pictures, we thus included catch trials. In these trials an arrow was superimposed onto the distractor picture (with random delays after picture onset). Whenever such an arrow appeared, participants' task was to first name the sound and then to indicate the direction of the arrow by a button press as a secondary response. Catch trial performance would thus inform us whether

participants indeed allocated attention to the screen and thus to the distractor pictures.

Method

Participants. We tested 24 native speakers of German (21 females, age: $M = 24.96$ years, $SD = 2.58$ years, age range: 20 – 29 years). In the experiments reported, most participants were students from Leipzig University. They received either course credit or 6 € (8 € in Experiments 2 and 3), reported normal or corrected-to-normal vision and normal hearing, and none of them was tested in more than one of the experiments. Sample size was determined in advance based on design considerations (to allow for counterbalancing of conditions across participants and items) and was the same as in related experiments (Mädebach et al., 2017).

Materials. Materials were the same as in Mädebach et al. (2017) but the functional role of the sounds and pictures differed. Thirty-two environmental sounds ($M = 1,246$ ms, $SD = 214$ ms, range: 702 ms – 1,572 ms) were used as targets and 32 corresponding pictures (black line drawings, size: 300 x 300 pixel, $8.4^\circ \times 8.4^\circ$ at 60 cm viewing distance) as distractors; these pictures were used to create all distractor conditions. In the congruent distractor condition, each sound was presented with the corresponding picture (e.g., bleating – sheep), in the semantically related distractor condition with a picture from the same semantic category (e.g., donkey), and in the unrelated distractor condition with a picture from a different semantic category (e.g., violin), see Appendix. In catch trials (included to draw participants' attention to the screen) each sound was paired with another picture from a different semantic category (e.g., hammer). In these trials, an arrow was presented superimposed on the picture and was flanked by three hashtags at each side (140 x 40 pixel, visual angle of $3.9^\circ \times 1.1^\circ$ at 60 cm viewing distance) to minimize the

chance for peripheral identification (Roelofs, 2008). In half of the trials the arrow pointed right (###>###), in the other half it pointed left (###<###). Eight additional sounds and corresponding pictures were selected for use in practice and warm-up trials.

Apparatus. The experiment was controlled by NESU (Nijmegen Experimental Setup). Sounds were presented via headphones at a comfortable listening volume. Pictures were presented on a 19-in. TFT-monitor (resolution: 1,280 x 1,024 pixel, background color: RGB 255 255 255). Vocal responses were registered from sound onset with a microphone connected to a hardware voice key. Manual responses in catch trials were registered with a push-button box.

Design. There were two fully crossed independent variables tested within participants and items: distractor condition (congruent, semantic, unrelated) and distractor SOA (-200 ms, 0 ms). Catch trials were treated as an additional distractor condition (also tested with both SOAs) but not included in the main analyses. Dependent variables were naming latency and error rate. Distractor SOAs were blocked. Distractor SOA sequence was counterbalanced across participants. Distractor conditions were presented intermixed within each block; the distribution of distractor conditions within a block and the sequence of distractor conditions (per item) was counterbalanced with a sequentially balanced Latin square. This resulted in 8 parallel experimental lists (4 counterbalanced conditions x 2 counterbalanced distractor SOAs), which were parallel with regard to the sequence of target sounds but different with regard to the sequence of distractor conditions (per target sound) and distractor SOAs. Three different pseudo-randomizations of these 8 parallel lists were created, resulting in 24 experimental lists overall (each used once).

Trials were pseudo-randomized using Mix (van Casteren & Davis, 2006) with the following constraints: (a) minimally four intervening trials between repetitions of

any given sound, (b) no repetition of any particular sequence of two specific sounds, (c) maximally two sounds from the same semantic category in consecutive trials, (d) no sounds with names starting with the same phoneme in consecutive trials, (e) minimally two intervening trials between picture repetitions, (f) no repetition of sounds and corresponding pictures in consecutive trials, (g) maximally three repetitions of any distractor condition.

Procedure. Participants were tested individually in a dimly lit room. They were separated from the experimenter by a partition wall. First, participants received written instructions informing them that their task would be to respond to environmental sounds as quickly and accurately as possible by saying the name of the entity associated with the sound. Then they were familiarized with the experimental materials (2 blocks with 40 trials each). In a first familiarization block, each sound was presented simultaneously with its corresponding picture. After 1 s, the sound's name appeared below the picture and after additional 3 s picture and name disappeared. Participants were asked to read the names out loud. In a second familiarization block, each sound was presented with its corresponding picture once more, but pictures remained only 800 ms on the screen and no target names were shown. Participants were asked to name the sounds as quickly as possible by using the names they had previously read. In a first practice block, the sound-picture interference task was introduced using practice sounds and pictures. Distractor SOA was the same as in the first experimental block (three congruent trials, nine unrelated trials). In a second practice block, catch trials with the arrow decision task were introduced (three congruent trials, nine unrelated trials including three catch trials). Participants were informed that in some trials an arrow would appear superimposed on the picture at some point in time. They were instructed that their primary task is to always name the sound as quickly as possible, but to pay attention to the screen as

well so that they could subsequently indicate the direction of the arrow whenever it would appear (left button press for arrows pointing to the left, right button press for arrows pointing to the right). After the practice blocks, the experimental trials were presented. There were small blocks consisting of two warm-up trials (using practice items) followed by 64 experimental trials, with short pauses between these blocks.

Experimental (and practice) trials were structured as follows. Distractor pictures were presented centered on the screen either before (distractor SOA -200 ms) or simultaneously with sound onset (distractor SOA 0 ms) and remained visible for 1.5 s. Verbal responses were registered up to 3 s from sound onset. Each trial lasted 4.8 s. In catch trials the arrow appeared at center position superimposed onto the picture with a random delay (200 – 999 ms) after picture onset and disappeared simultaneously with picture offset. Overall, an experimental session lasted about 45 minutes.

Analytical Approach. Data were analysed with mixed effect models treating participants and items as crossed random factors (Baayen, Davidson, & Bates, 2008). Models were fitted in R (R Core Team, 2019) using the package lme4 (Bates, Maechler, Bolker, & Walker, 2015). Naming latencies were analysed with linear mixed models, error data were analysed with generalised linear mixed models (binomial family). Additional latency analyses on log-transformed latencies, analyses fitting untransformed latencies to a Gamma distribution, and by-participant and by-item ANOVAs on untransformed latencies lead to the same conclusions as the analyses presented here. Documented analyses scripts for all analyses are available via the OSF (<https://osf.io/wqbmA/>).

We aimed to include the maximal random structure allowed by our data (Barr, Levy, Scheepers, & Tily, 2013). We started out with a maximal model containing random slopes for distractor condition, SOA, and their interaction for both participants

and items. In case of non-convergence, we reduced model complexity by stepwise removing random correlations, random slopes of interaction parameters, and random slopes for simple effects (each first for items) until convergence was reached. In case of singular model fits, we excluded random correlations, followed by excluding random slopes which were estimated to be (close to) zero. Significance of fixed effects was evaluated in the following way. We fitted reduced models excluding the interaction, or the interaction and one of the main effects and used likelihood ratio model comparisons to evaluate the significance of the two main effects and their interaction. Significance of the two condition contrasts of interest (congruent vs. unrelated, semantic vs. unrelated) and their change across SOA was determined based on the corresponding parameter estimate using the Satterthwaite approximation of degrees of freedom provided by lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017). In all models, SOA was sum coded and distractor condition was treatment coded using the unrelated condition as the baseline. Therefore, the intercept in the models reflects the estimated mean response across SOAs in the unrelated condition, the SOA parameter reflects the SOA effect in the unrelated condition, the two condition parameters reflect the respective distractor effects across SOAs, and the two interaction parameters reflect the estimated change of the respective distractor effect across SOAs.

Results

Accuracy of the verbal responses was checked online by the experimenter. Catch trials were excluded from further analyses. Performance in the catch trials was generally very high (correct responses: $M = 97.3\%$, $SD = 2.5\%$, range: 90.6% – 100%), demonstrating that participants followed the instruction and attended to the screen. Latencies in the remaining trials were removed from analysis when any of the following occurred: (a) incorrect or missing response, (b) disfluent speech, (c) non-

speech sound (e.g., opening of the lips) of the participant triggering the voice key, (d) technical errors (e.g., voice key triggered by outside noise), (e) recorded latency was ≤ 300 ms or ≥ 3000 ms (the response deadline). Overall, 361 experimental trials (7.8%) were discarded from the latency analyses. Trials of type (a) – (c) were counted as errors in the error analyses (356 trials, 7.7%). Figure 1 illustrates the latency results (by participants). Table 1 shows the fixed effect estimates for the latency and error data.

For naming latencies, the interaction between distractor condition and distractor SOA was not significant, $\chi^2(2) = 1.03$, $p = .598$. There was a significant main effect of distractor SOA, reflecting longer latencies with distractor SOA 0 ms than with SOA -200 ms, $\chi^2(1) = 10.77$, $p = .001$. There was also a significant main effect of distractor condition, $\chi^2(2) = 78.77$, $p < .001$. Compared to the unrelated condition, naming latencies were significantly shorter in the congruent condition and significantly longer in the semantic condition (see Table 1). For errors, the interaction between distractor SOA and distractor condition, $\chi^2(2) = 1.84$, $p = .398$, and the main effect of distractor SOA, $\chi^2(1) < 0.01$, $p = .982$, were not significant. The main effect of distractor condition was significant, $\chi^2(2) = 99.40$, $p < .001$. Compared to the unrelated condition, significantly fewer errors were made in the congruent condition and more errors were made in the semantic condition (see Table 1).

Figure 1. Latency results from Experiment 1. The left panel displays mean naming latencies as estimated in the model fit (filled shapes, solid lines) and as calculated on the raw data (empty shapes, dashed lines). The right panel displays latency differences between the unrelated condition and, respectively, the semantic and congruent conditions as estimated in the model fit (big filled shapes, solid lines) and as calculated on the raw data (big empty shapes, dashed lines). Small empty shapes and densities represent the observed latency differences by participants. Error bars in both panels represent the 95% confidence interval around the estimated means.

Table 1. Fixed effect estimates for latency and error data in Experiment 1.

	Latencies					Errors			
	Estimate	SE	df	t	p	Estimate	SE	z	p
Intercept	1127	37				-2.67	0.19		
SOA	34	10	55.4	3.23	.002	-0.01	0.13	-0.11	.915
Congruent	-223	16	36.1	-13.78	<.001	-1.32	0.18	-7.36	<.001
Semantic	56	14	35.4	3.87	<.001	0.25	0.12	2.05	.041
SOA x congruent	-9	10	4087.6	-0.82	.412	0.21	0.18	1.19	.233
SOA x semantic	1	11	4084.4	0.10	.920	-0.03	0.12	-0.21	.831

Note. The latency model contains random slopes for SOA (participants, items) and distractor condition contrasts (items). The error model contains random slopes for SOA (participants, items). The intercept corresponds to the estimated mean in the unrelated distractor condition across distractor SOA.

Discussion

Compared to unrelated distractor pictures, sound naming was faster and less error prone with congruent distractor pictures and slower and more error prone with semantically related distractor pictures. Both effects did not differ across distractor SOAs. These results demonstrate the feasibility of chronometric studies of sound naming. Both effects show that distractor pictures were processed sufficiently to influence sound naming and, respectively, that sound naming latencies (and error rates) were susceptible to the distractor manipulation. Furthermore, the observation of semantic interference from distractor pictures in sound naming supports the view that semantic interference effects are not restricted to task configurations involving target pictures and distractor words, distractor pictures or distractor sounds, but appear to extend to other task configurations as well (see also La Heij, Starreveld, & Steehouwer, 1993; Starreveld & La Heij, 1995). Before discussing the theoretical implications of these results in further depth, we present two more experiments which aimed at (a) replicating congruency facilitation and semantic interference in our task configuration and (b) exploring whether they are related to response selection or earlier processes. However, before doing so, we briefly discuss some notable secondary observations in Experiment 1.

Mean sound naming latencies (in the unrelated condition) were well above 1,000 ms which is longer than typical picture naming latencies in comparable studies. For instance, mean naming latencies were below 700 ms in picture naming experiments with sound distractors when the same materials, target responses, and a very similar familiarization procedure as the present experiment were used (Mädebach et al., 2017). One likely cause for the slower sound naming responses is that perceptual identification takes longer for the sounds because they have a natural temporal duration and have to unfold over some time before they can be identified. A

second cause might be higher uncertainty when selecting an appropriate label for the sound. For the environmental sounds not only name alternatives at different levels of abstractions (like sheep vs. animal) but also different aspects of what to describe in the sound come into play. For instance, some sounds might be plausibly labeled according to their abstract source (e.g., car), their more concrete source (e.g., car horn), or the action producing the sound (e.g., honking).

Similar to the overall latencies, the size of the semantic effects we observed in sound naming is also larger than corresponding effects typically observed in picture naming studies. For instance, congruency facilitation effects in picture naming amounted to ca. 100 ms with distractor words (Glaser & Döngelhoff, 1984) and with distractor pictures (Jescheniak et al., 2009). Similarly, semantic interference in picture naming rarely exceeds 30 – 40 ms with distractor words (e.g., Alario, Segui & Ferrand, 2000; Damian & Martin, 1999; Geng et al., 2013; Lupker, 1979; Schriefers et al., 1990; cf. Glaser & Döngelhoff, 1984). The larger effects in sound naming might, at least in part, reflect a scaling up of the effect with increasing overall latencies. However, they might also reflect, as mentioned above, that selecting the appropriate name is more difficult in sound naming (due to weaker connections between sound input and associated semantic-lexical representations) and hence priming by congruent distractors might be more beneficial and increased competition with semantically related distractors more detrimental in sound naming.

The SOA range in which we observed the context effects corresponds to the one in which corresponding effects in picture naming have been typically observed (e.g., Glaser & Döngelhoff, 1984; Mädebach et al., 2017). This might be seen as somewhat surprising given the longer latencies in sound naming. If these are mostly due to, as we argue above, prolonged perceptual identification and lexical selection, then more positive distractor SOAs (i.e., distractor picture onset after target sound

onset) would be needed in sound naming than in picture naming to similarly align distractor processing with semantic-lexical processing of the target. However, when comparing the time course of visual and auditory distractor words, Damian and Martin (1999) found that effects of visual distractor words extend over a broader SOA range than the same effects with auditory distractor words. They argued that “visual distractors unintentionally activate their lexical representations while they remain on the screen” (Damian & Martin, 1999, p. 351). Following this reasoning, distractor effects with distractor pictures might be relatively robust to variations in relative processing speed. If so, however, a manipulation of distractor SOA cannot be used to infer about the locus of the context effects during target processing. Therefore, we used a different approach in Experiments 2 and 3.

Experiment 2

The aim of Experiment 2 was (a) to replicate congruency facilitation and semantic interference observed in Experiment 1 and (b) to explore the locus of the effects. Previous studies on cross-modal interactions in the processing of environmental sounds and pictures have suggested that congruent sounds facilitate early perceptual processes like object identification (Chen & Spence, 2010, 2011; Iordanescu et al., 2010; Yuval-Greenberg & Deouell, 2009). Furthermore, some authors have argued for a perceptual locus of semantic interference (Dell’Acqua, Job, Peressotti, & Pascali, 2007; van Maanen, van Rijn, & Borst, 2009, cf. Piai, Roelofs, & Roete, 2015; Piai, Roelofs, & Schriefers, 2014; Schnur & Martin, 2012). In Experiment 2, we therefore explored whether congruency facilitation and semantic interference from distractor pictures in sound naming arise (in part) during processes preceding response selection. We used a psychological refractory (PRP) approach and combined the sound-picture interference task from Experiment 1 with a simple

visual discrimination task. The discrimination task corresponded to the arrow decision task used in the catch trials in Experiment 1 (catch trials were not needed in Experiment 2 because the visual discrimination task ensured that participants' attention was effectively drawn to the screen). Participants were asked to first indicate the direction of the arrow with a button press (T1) before naming the sound (T2). Arrow and sound were either presented simultaneously (short task SOA 0 ms) or the sound was presented with a fixed delay (long task SOA 500 ms). Other than in Experiment 1, we did not vary distractor SOA but used only distractor SOA 0 ms at which congruency facilitation and semantic interference were observed. We expected dual-task interference, that is, longer response latencies in sound naming (T2) with the short task SOA as compared to the long task SOA. Of critical interest was how this dual-task interference would affect distractor effects in sound naming. Specifically, if congruency facilitation or semantic interference from distractor pictures in sound naming arise (in part) during pre-central processes the respective effect should be underadditive with task SOA (i.e., should be reduced at the short task SOA). In contrast, if congruency facilitation or semantic interference arise during later response selection processes, the respective effect should be additive with task SOA.

Method

Participants. We tested 24 native speakers of German (20 females, age: $M = 24.25$ years, $SD = 5.44$ years, age range: 19 – 39 years).

Materials and Apparatus. Same as in Experiment 1.

Design and Procedure. Design and procedure differed as follows from Experiment 1. The arrow decision task previously used in catch trials now served as T1 in all trials. Other than in Experiment 1, the arrows were presented directly above

or below the pictures (with equal probability, position randomly varying from trial to trial). This modification was introduced to avoid that the ease of arrow and picture perception would differ for short and long task SOAs.¹ The sound naming task from Experiment 1 served as T2. The arrow decision task in the former catch trials was discarded (because participants' attention was directed to the screen by the T1 stimuli). However, we retained the respective trials (with unrelated distractors as before) as filler trials to keep the experiment as parallel to Experiment 1 as possible (i.e., to have the same number of stimulus repetitions, the same proportions of conditions, and the same counterbalancing procedure). Task SOA was manipulated in two steps (short – 0 ms, long – 500 ms). During the construction of experimental lists, there were two blocks. Within each block, short and long task SOAs appeared equally often and (pseudo-)randomly varied from trial to trial. However, for a given item, task SOA was fixed in each block. That is, half of the items were presented with the short task SOA in the first block and with the long task SOA in the second block. For the other half of the items, the reverse was true. The assignment of item subsets to the sequence of task SOAs was counterbalanced across participants.

As in Experiment 1, there were 8 parallel experimental lists (4 counterbalanced distractor conditions x 2 counterbalanced task SOAs) and three pseudo-randomizations of these lists, resulting in 24 experimental lists overall (each used once). Randomization criteria were the same as in Experiment 1 with the following changes: (a) repetition of arrow direction, arrow position and task SOA on

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¹ With the superimposed presentation mode used in Experiment 1, arrow recognition and picture recognition would have been impaired with the short but not the long task SOA, complicating any comparison across task SOAs. This was not an issue in Experiment 1, because arrow recognition was always affected by the (background) picture and, more important, because only response accuracy, not latency was critical in the secondary task (and primary task performance was not analyzed for catch trials).

maximally three consecutive trials, (b) not more than one repetition of any particular sequence of three (instead of two) specific sounds.

The familiarization phase was identical to Experiment 1. The practice phase was adapted. A first practice block (12 trials) introduced the arrow decision task. A second practice block (12 trials) introduced the sound naming task with distractor pictures (similar to Experiment 1). A third practice block (12 trials) introduced the dual-task situation. Participants were instructed to always respond first with a button press to indicate the direction of the arrow and then to name the sound. Participants were asked to always respond as quickly and accurately as possible, while following the instructed task order. After the practice blocks, the experimental trials were presented. There were small blocks consisting of two warm-up trials with practice items followed by 64 experimental trials, with short pauses in between.

Experimental (and practice) trials were structured as follows. First, a fixation cross was presented for 500 ms at the center of the screen followed by 100 ms blank screen. Then an arrow (same as in Experiment 1) appeared for 500 ms either 180 pixels above or 180 pixels below the center of the screen. Sound stimuli started either simultaneously with or 500 ms after the onset of the arrow, depending on task SOA. Pictures appeared simultaneously with sound onset at the center of the screen and remained visible for 1.5 s. Responses were registered until 3 s after sound onset. An experimental session lasted about 45 minutes.

Results

Response latencies and error rates were analyzed separately for both tasks. The filler condition was excluded from further analysis.² In the arrow decision task, 67

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² Naming latencies were very similar for the unrelated condition ($M = 1,159$ ms, $SD = 111$ ms) and the filler condition ($M = 1,164$ ms, $SD = 122$ ms).

observations (1.5%) were coded as errors and entered into the error analyses, including (a) false or missing responses and (b) responses that occurred in the wrong order (i.e., after sound naming). In the sound naming task, the same error criteria were applied as in Experiment 1, but additionally included responses that occurred in the wrong order (i.e., before pressing a button). As a result, 404 observations (8.8%) were removed from the latency analysis in the sound naming task. Again, only errors made by the participants were entered into the error analyses (364 observations, 7.9%). Trials with an erroneous response were discarded from the latency analysis of the respective task. Latency and error data for each task were analysed as detailed for Experiment 1. For T1 only participants were included as a random factor (because there were only two different stimuli. Figure 2 illustrates the latency results (by participants). Table 2 shows the fixed effect estimates for the latency and error data.

Figure 2. Latency results from Experiment 2. The left panel displays mean response latencies as estimated in the model fit (filled shapes, solid lines) and as calculated on the raw data (empty shapes, dashed lines). The right panel displays latency differences between the unrelated condition and, respectively, the semantic and congruent conditions as estimated in the model fit (big filled shapes, solid lines) and as calculated on the raw data (big empty shapes, dashed lines). Small empty shapes and densities represent the observed latency differences by participants. Error bars in both panels represent the 95% confidence interval around the estimated means.

Table 2. Fixed effect estimates for latency and error data in Experiment 2.

	Latencies					Errors			
	Estimate	SE	df	t	p	Estimate	SE	z	p
Arrow decision (T1)									
Intercept	624	17				-4.513	0.301		
SOA	15	7	35.1	2.19	.035	0.435	0.242	1.79	.073
Congruent	-14	5	4493.1	-2.84	.005	-0.21	0.335	-0.63	.532
Semantic	2	5	4493.1	0.42	.676	-0.34	0.341	-1.00	.319
SOA x congruent	-6	5	4493.1	-1.11	.269	0.269	0.335	0.80	.422
SOA x semantic	7	5	4493.1	1.32	.187	0.139	0.341	0.41	.684
Sound naming (T2)									
Intercept	1192	34				-2.61	0.194		
SOA	81	9	98.4	9.42	<.001	0.043	0.09	0.47	.636
Congruent	-175	19	33.9	-9.12	<.001	-1.203	0.228	-5.27	<.001
Semantic	90	21	31.6	4.23	<.001	0.177	0.166	1.07	.285
SOA x congruent	39	11	3990.4	3.65	<.001	-0.167	0.165	-1.01	.311
SOA x semantic	-6	11	3992.8	-0.57	.571	0.008	0.122	0.07	.948

Note. The T1 latency model contains random slopes for SOA (participants). The T2 latency model contains random slopes for SOA and distractor condition contrasts (participants, items). The T1 error model contains the random slope for SOA (participants). The T2 error model contains the random slopes for the distractor condition contrasts (items). The intercept corresponds to the estimated mean in the unrelated distractor condition across task SOA.

T1: Arrow decision. For response latencies, the interaction between distractor condition and task SOA was not significant, $\chi^2(2) = 5.90$, $p = .052$. Overall response latencies were longer at the short task SOA than at the long task SOA, $\chi^2(1) = 5.43$, $p = .020$. The main effect of distractor condition was also significant, $\chi^2(2) = 12.41$, $p = .002$. Response latencies were significantly shorter in the congruent condition than in the unrelated condition but there was no significant difference between the unrelated and the semantic condition (see Table 2). For errors, there was no significant interaction between distractor condition and task SOA, $\chi^2(2) = 0.66$, $p = .720$, and no significant main effect of distractor condition, $\chi^2(2) = 0.88$, $p = .645$. But there was significant main effect of task SOA, $\chi^2(2) = 10.15$, $p = .001$, reflecting more errors at the short task SOA.

T2: Sound naming. For naming latencies, there was a significant interaction between distractor condition and task SOA, $\chi^2(2) = 21.01$, $p < .001$. There was also a significant main effect of task SOA, $\chi^2(2) = 61.41$, $p < .001$, reflecting longer latencies at the short task SOA than at the long task SOA. The main effect of distractor condition was also significant, $\chi^2(2) = 59.25$, $p < .001$. Naming latencies were significantly shorter in the congruent condition than in the unrelated condition with the effect changing significantly across task SOA (see Table 2). The congruency effect was smaller at the short task SOA, but significant at each task SOA, $ps < .001$. Naming latencies were longer in the semantic condition compared to the unrelated condition; this effect did not differ significantly across task SOA (see Table 2). In order to estimate the evidence for and against the critical interaction with task SOA for both contrasts, we additionally computed Bayes factors based on the Bayesian Information Criterion (BIC) according to the formula as stated by Wagenmakers (2007, p. 796). To this end, we fitted additional models which omitted either the interaction effect for the congruency contrast or the interaction effect for the semantic contrast. The BIC-approximation Bayes factors suggest positive evidence in favour of the interaction for the congruency contrast ($BF_{10} = 11.7$), and strong evidence against the interaction for the semantic contrast ($BF_{01} = 55.2$). For errors, there was no significant interaction between distractor condition and task SOA, $\chi^2(2) = 1.19$, $p = .551$, and no significant main effect of task SOA, $\chi^2(2) = 0.12$, $p = .731$. But there was a significant main effect of distractor condition, $\chi^2(2) = 29.63$, $p < .001$. Compared to the unrelated condition, significantly fewer errors were made in the congruent condition, whereas there was no significant difference between the semantic and the unrelated condition (see Table 2).

Discussion

As expected, we observed dual-task interference, that is, sound naming in T2 was slower at the short task SOA compared to the long task SOA. We also replicated congruency facilitation and semantic interference in sound naming from Experiment 1. The congruency facilitation effect was underadditive with dual-task interference, that is, it was smaller at the short compared to the long task SOA. This suggests that the congruency facilitation effect arises, at least in part, during pre-central processing preceding response selection. The semantic interference effect, in contrast, did not differ significantly between task SOAs. This suggests that the semantic interference effect arises for the most part (or even exclusively) during response selection or later processes.

Unexpectedly, we also observed an effect of task SOA on arrow decision in T1. T1 responses were slower and more error prone at the short task SOA compared to the long task SOA. This is at odds with predictions of the central bottleneck theory of PRP performance. However, similar effects have been found in several other studies (e.g., Hommel, 1998; Logan & Schulkind, 2000; Miller, 2006; Miller & Alderton, 2006) and it has been argued that this is an indication that central processes of T1 and T2 might proceed in parallel to some degree (see Tombu & Jolicoeur, 2003). However, importantly, adopting a capacity sharing account of dual-task interference would not change the predictions regarding the (under-) additivity of dual-task interference and the picture-sound interference effects in T2 (Tombu & Jolicoeur, 2003).

Another unexpected finding was that participants classified the arrows more quickly with congruent sound-picture pairs in T2. Additional analyses showed that the T1 congruency effect persisted when trials were excluded in which T1 and T2 responses were initiated in close temporal proximity (inter-response time < 200 ms). This suggests that the effect was not caused by strategic response grouping by the

participants (see Pashler & Johnston, 1989). It is thus unclear what might have caused this unexpected finding. We refrain from speculating about its origin because it was not replicated in Experiment 3 and, therefore, might have been a spurious observation.

As in Experiment 1, sound naming latencies in T2 were relatively long (ca. 1,100 ms in the unrelated condition with the long task SOA). Response latencies in the arrow decision task in T1 were much shorter (ca. 600 ms). Because of this fact, one might argue that Experiment 2 might not have been sensitive enough to detect a modulation of the semantic interference effect in T2 at the short task SOA. If, as we argued above, the increase in sound naming latencies compared to picture naming latencies reflects mainly prolonged pre-lexical processing (sound identification), then the processing duration of T1 might not have been long enough to generate a cognitive slack large enough to absorb the pre-central processing of the target sounds (in the unrelated condition) completely. If one assumes that pre-lexical processing in picture naming takes about 200 ms (see Indefrey, 2011), it might well be that pre-lexical processing in sound naming takes about, say, 500 ms, because the stimuli unfold over time and are possibly less easily identified. Consequently, pre-central processing in sound naming might not have been completed by the time response selection processes in the arrow decision task were finished (in some proportion of trials). If so, the arrow decision task might not have created a large enough cognitive slack able to absorb (the part of) the semantic interference effect possibly arising during pre-central processes in sound naming. We want to note that the significant reduction of the congruency facilitation effect at the short task SOA suggests that the design of Experiment 2 was, in principle, sensitive enough to detect underadditivity of dual-task interference and the distractor effects in T2. However, given that semantic interference was much smaller than congruency facilitation, it is

hard to rule out that the design – while sensitive enough to pick up the modulation of the large-sized congruency facilitation – was not sufficiently sensitive to a similar modulation of the smaller-sized semantic interference. We addressed this issue in another dual-task experiment with a revised procedure (Experiment 3).

Experiment 3

Experiment 3 was similar to Experiment 2 in that a discrimination task as T1 was combined with sound naming as T2. However, we implemented two changes to increase the sensitivity of the procedure to detect potential modulations of semantic interference across task SOAs. First, we used a more demanding letter rotation task (e.g., Kung & Hamm, 2010; Milivojevic, Hamm, & Corballis, 2011; Núñez-Peña & Aznar-Casanova, 2009) as T1. Participants were presented with rotated letters in either standard or vertically mirrored orientation and asked to indicate the letter orientation (standard vs. mirrored) by pressing a corresponding button. The higher task demands should increase the cognitive slack created during T1 processing. Second, the long task SOA was changed to 1,500 s (from 500 ms), to increase the temporal separation between T1 and T2 (at the long task SOA).

Method

Participants. We tested 24 native speakers of German (16 females, age: $M = 21.42$ years, $SD = 3.03$ years, age range: 19 – 32 years).

Materials, Apparatus, Design and Procedure. Identical to Experiment 2 with the following exceptions: Targets in the manual T1 were eight uppercase letters (B, F, G, K, L, P, Q, Z). These letters were presented in Arial font, centered on a square with a size of 75 x 75 pixels (visual angle of $2.1^\circ \times 2.1^\circ$ at 60 cm viewing distance). They were rotated either by 150° or 210° in clockwise direction and occurred either in

standard or vertically mirrored orientation (i.e., there were four versions per letter).

This choice was based on a pilot study of the letter rotation task ($N = 12$) in which we had observed a (sufficiently large) average response latency of 1,193 ms ($SD = 194$ ms) for these angles. For the letter rotation task, participants were instructed to decide via a button press whether the letter was in standard orientation (right button) or mirrored (left button). As in Experiment 2, the T1 stimuli (letters) were presented above or below the T2 distractor pictures (position randomly varying from trial to trial). Each letter was combined with four target sounds, so that the letter was neither included in the target name nor in the name of the corresponding distractor pictures. As a result, a given letter occurred across all distractor conditions and task SOAs of a specific target sound. Letter orientation (standard or mirrored), letter position (above or below the pictures) and letter rotation (150° or 210°) remained constant for a given sound and participant, but were balanced across all letters per participant. Randomization criteria were the same as in Experiment 2 with the following adjustments: (a) minimally two intervening trials before letter repetitions and (b) maximally three repetitions of the same letter orientation, letter position, and letter rotation in consecutive trials.

Results

Data were treated and analyzed as described for Experiment 2. The filler condition was again excluded from further analysis.³ In the letter rotation task, 500 observations (10.9%) were coded as errors and entered into the error analyses. It turned out that participants were not able to differentiate between standard and mirrored versions of the letter “Z” (average error rates with 48.0% at about chance

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³ As in Experiment 2, average naming latencies were similar for the unrelated condition ($M = 1,441$ ms, $SD = 159$ ms) and the filler condition ($M = 1,443$ ms, $SD = 162$ ms).

level). However, reassuringly, additional analyses in which trials containing the letter “Z” were excluded from T2 analyses or in which all trials with errors in T1 were excluded from T2 analyses did not change the results in any meaningful way. In the sound naming task, 649 trials (14.1%) were coded as erroneous, of which 497 observations (10.8%) were entered into the error analyses. Latency and error data for each task were analysed as detailed for Experiment 1. For T1 again, only participants were included as a random factor. Figure 3 illustrates the latency results (by participants). Table 3 shows the fixed effect estimates for the latency and error data.

Figure 3. Latency results from Experiment 3. The left panel displays mean response latencies as estimated in the model fit (filled shapes, solid lines) and as calculated on the raw data (empty shapes, dashed lines). The right panel displays latency differences between the unrelated condition and, respectively, the semantic and congruent conditions as estimated in the model fit (big filled shapes, solid lines) and as calculated on the raw data (big empty shapes, dashed lines). Small empty shapes and densities represent the observed latency differences by participants. Error bars in both panels represent the 95% confidence interval around the estimated means.

Table 3. Fixed effect estimates for latencies and error data in Experiment 3.

	Latencies					Errors			
	Estimate	SE	df	t	p	Estimate	SE	z	p
letter rotation (T1)									
Intercept	1015	33				-2.207	0.122		
SOA	40	9	158.5	4.49	<.001	0.182	0.084	2.17	.030
Congruent	-1	12	4062	-0.07	.942	-0.001	0.118	-0.01	.992
Semantic	16	12	4063	1.30	.192	0.053	0.118	0.45	.652
SOA x congruent	4	12	4062.6	0.34	.730	-0.049	0.118	-0.41	.681
SOA x semantic	13	12	4062.4	1.05	.296	0.053	0.118	0.45	.652
sound naming (T2)									
Intercept	1485	41				-2.391	0.203		
SOA	275	23	46.8	12.06	<.001	0.238	0.107	2.23	.026
Congruent	-155	19	32.3	-8.19	<.001	-0.905	0.148	-6.11	<.001
Semantic	90	20	30.6	4.56	<.001	0.218	0.154	1.41	.157
SOA x congruent	70	13	3755.2	5.43	<.001	-0.049	0.141	-0.35	.728
SOA x semantic	14	13	3764.4	1.07	.283	0.023	0.113	0.20	.841

Note. The T1 latency model contains random slopes for SOA (participants). The T2 latency model contains random slopes for SOA and the distractor condition contrasts (participants, items). The T1 error model contains no random slopes. The T2 error model contains random slopes for SOA (participants, items) and the distractor condition contrasts (items). The intercept corresponds to the estimated mean in the unrelated distractor condition across task SOA.

T1: Letter rotation. For response latencies there was no significant interaction between distractor condition and task SOA, $\chi^2(2) = 1.14$, $p = .567$, and no significant main effect of distractor condition, $\chi^2(2) = 2.33$, $p = .312$. The main effect of task SOA was significant, $\chi^2(1) = 32.30$, $p < .001$, reflecting longer latencies at the short task SOA than at the long task SOA. For errors, there was no significant interaction, $\chi^2(2) = 0.74$, $p = .689$, and no significant main effect of distractor condition, $\chi^2(2) = 0.41$, $p = .813$. But there was a significant main effect of task SOA, $\chi^2(1) = 14.67$, $p < .001$, reflecting more errors at the short task SOA than at the long task SOA.

T2: Sound naming. For naming latencies there was a significant interaction between distractor condition and task SOA, $\chi^2(2) = 32.88$, $p < .001$. There was also a significant main effect of task SOA, $\chi^2(1) = 59.20$, $p < .001$, reflecting longer latencies at the short task SOA than at the long task SOA. The main effect of distractor condition was also significant, $\chi^2(2) = 60.98$, $p < .001$. Naming latencies were significantly shorter in the congruent condition than in the unrelated condition with the effect changing significantly across task SOA (see Table 3). The congruency effect was smaller at the short task SOA than at the long task SOA, but it was significant at each task SOA, $ps < .001$. Naming latencies were longer in the semantic condition compared to the unrelated condition. This effect did not differ significantly across task SOAs (see Table 3). The BIC-approximation Bayes factors suggest very strong evidence in favour of the interaction for the congruency effect ($BF_{10} = 36,837.5$), and strong evidence against the interaction for the semantic effect ($BF_{01} = 35.4$). For errors, we found no significant interaction of task SOA and distractor condition, $\chi^2(2) = 0.26$, $p = .880$. The main effect of task SOA was significant, $\chi^2(1) = 7.16$, $p = .007$, reflecting more errors at the short task SOA. The main effect of distractor condition was significant, $\chi^2(2) = 33.62$, $p < .001$. Compared to the unrelated condition, significantly fewer errors were made in the congruent condition, whereas there was no significant difference between the semantic and the unrelated condition (see Table 3).

Discussion

Experiment 3 replicated the main results of Experiment 2. There was again dual-task interference, that is, T2 sound naming latencies were slower at the short task SOA compared to the long task SOA. Congruency facilitation and semantic interference from distractor pictures in sound naming were also replicated. Most

importantly, congruency facilitation was again underadditive with dual-task interference (i.e., smaller with the short task SOA than with the long task SOA) whereas semantic interference again appeared to be largely additive with dual-task interference (i.e., of similar magnitude across task SOA). In the letter rotation task, participants responded generally more slowly and less accurately with the short task SOA compared to the long task SOA. This is similar to what we found with the arrow decision task in Experiment 2 and suggests that T2 processing had some influence on T1 processing (see Discussion of Experiment 2).

Importantly, changing the manual discrimination task from arrow decision (in Experiment 2) to letter rotation (in Experiment 3) had the intended effect. Response latencies in T1 increased markedly from ca. 600 ms to ca. 1,000 ms. Thus, Experiment 3 should have been sensitive enough to detect a possible modulation of the semantic interference effect across task SOAs. Sufficient sensitivity to detect a modulation of a distractor effect, to the extent that it exists, is also suggested by the clear modulation of the congruency effect. The results of Experiment 3 therefore align with those of Experiment 2 in that they suggest that the congruency facilitation effect arises, partly, during early pre-central processing stages, whereas the semantic interference effect arises during central (response selection) or post-central processing stages.

General Discussion

In three experiments participants named environmental sounds in the presence of distractor pictures. In all experiments, we observed facilitation from congruent distractor pictures and interference from semantically related distractor pictures relative to unrelated distractor pictures. These results correspond to similar effects observed in picture naming with distractor words (e.g., Glaser & Döngelhoff,

1984) or distractor sounds (Mädebach et al., 2017) and suggest that both effects are neither specific to the use of target pictures nor to the use of distractor words (cf. Mahon et al., 2007). Experiments 2 and 3 used a dual-task design, in which sound naming (T2) was combined with a manual (arrow or letter) discrimination task (T1). Congruency facilitation was underadditive with dual-task interference, which suggest that it arises at least partially during pre-central processes preceding response selection in sound naming. In contrast, semantic interference was additive with dual-task interference, which suggests that it arises during response selection or later processing stages in sound naming.

The present results demonstrate the feasibility of using sound naming tasks for chronometric investigations of word production. This is a valuable observation because experimental tasks which allow well-controlled manipulations of conceptually mediated word production are rare. So far, the vast majority of such studies has relied on using target pictures (in picture naming or picture categorization tasks) or target words (in word translation or word categorization tasks). We believe that sound naming might provide a valuable addition to the limited experimental toolbox in word production research. For example, sound naming latencies are much longer than typical picture naming latencies. As we argued above, this might be due to (a) the natural temporal duration of sounds, which leads to a longer duration of perceptual processes than in picture naming and (b) larger uncertainty in matching appropriate names to sounds than to pictures. It might be that, as a consequence, sound naming could provide a more sensitive instrument to tap processing mechanisms at the interface between the semantic and the lexical level because effects arising at this interface are magnified in sound naming compared to picture naming. At a more general level, our results suggest that sound naming is a task suitable for exploring semantic processing in general.

The similarity of semantic context effects in picture naming with distractor sounds (Mädebach et al., 2017) and in sound naming with distractor pictures (the present study) suggests common underlying causes in both tasks. The semantic interference effects observed in both tasks (and in picture-word and picture-picture interference tasks) can be explained by competitive selection of amodal semantic-lexical representations involved in both picture and sound naming (see below for further discussion). In contrast, the congruency facilitation effect appears to be (partially) caused by earlier processes which may involve more modality-specific semantic representations (Chen & Spence, 2018). Previous studies investigating the effects of environmental sounds on processing target pictures demonstrated that environmental sounds increase visual sensitivity (Chen & Spence, 2011), improve goal-directed visuo-spatial attention (Iordanescu et al., 2008, 2010, Kvasova et al., 2019), and facilitate picture identification and categorisation (Chen & Spence, 2010, 2018). The present results suggest that cross-modal interactions are bidirectional in nature, that is, that congruent context pictures have a similarly facilitatory effect on the perceptual processing of sounds as context sounds have on the perceptual processing of pictures (see also Schneider et al., 2008; Yuval-Greenberg & Deouell, 2009).

Congruency facilitation effects are predicted by all current models of word production because overlapping representations for congruent targets and distractors would be expected to ease processing of a target, regardless of whether competitive or non-competitive selection is assumed. In principle, congruency facilitation could arise across semantic, lexical, and sub-lexical processing stages to the extent that these representations are activated in the course of processing of the distractor. Indeed, the results of Experiments 2 and 3 support that congruency facilitation has multiple sources. In these dual-task experiments, congruency facilitation was

reduced (although still present) at the short task SOA. The persistence of a sizeable “residual” effect suggests that central (or post-central) processing stages (e.g., lexical selection) substantially contributed to the overall congruency effect. However, the reduction of the congruency effect at the short task SOA suggests that congruent distractor pictures also affected earlier, pre-central processes (i.e., sound identification).

The finding of underadditivity of the congruency effect and dual-task interference seems to be inconsistent with the result from a related study from our lab (Mädebach, Kieseler, & Jescheniak, 2018). In this earlier study participants named pictures in the presence of distractor sounds (distractor SOA -200 ms; T2), following a visual shape discrimination task (T1). In this situation, the congruency effect was additive with task SOA. We had predicted underadditivity, because the results of other studies suggested facilitated visual processing and picture identification by congruent sounds (Chen & Spence, 2010, 2011). We hypothesised that the unexpected result in our study may be explained by the particular choice of distractor SOA. Distractor SOA of -200 ms was chosen because we expected the (for this study) critical semantic interference to be largest at this SOA. However, because sounds have a natural temporal duration and are processed slower than pictures, processing of the distractor sounds at this particular distractor SOA may not have progressed far enough to affect early perceptual processing of the target picture. In line with this assumption, we had observed that the congruency facilitation effect from distractor sounds was substantially larger at a more negative distractor SOA (i.e., distractor SOA -800 ms, Mädebach et al., 2017). The larger facilitation effect with more negative distractor SOA may reflect that with a sufficiently large “head start” of sound processing (i.e., a long negative distractor SOA), contributions to congruency facilitation come from perceptual identification as well as semantic-lexical (and later)

processes in picture naming, whereas with a short “head start” (i.e., a short negative distractor SOA), perceptual and conceptual contributions to the effect become smaller. In other words, the distractor SOA used in the previous study may not have been adequate to detect such contributions to the effect. The situation is different for the present study, because the relative processing speeds of target and distractor are reversed (i.e., quickly processed distractor pictures and slowly processed target sounds). At SOA 0 ms, the distractor pictures’ “head start” was likely long enough to already affect identification of the target sounds which resulted in underadditivity of the effect with dual-task interference. In sum, we assume that congruent sound-picture pairs, in principle, can facilitate pre-central processes (i.e., picture and sound identification), regardless of whether the sound or the picture is the target if distractor processing has progressed sufficiently in time.

The observation of semantic interference with distractor pictures in sound naming is theoretically informative for the debate about lexical selection mechanisms in word production. Empirically, this observation adds to the available evidence that semantic interference is not restricted to distractor words (Aristei et al., 2012; Jescheniak et al., 2014; Mädebach et al., 2017, Mädebach, Wöhner, & Jescheniak, 2018, Matushanskaya et al., 2016; cf. Finkbeiner & Caramazza, 2006; Mahon et al., 2007). Furthermore, the observation that this effect is additive with dual -task interference corresponds to similar evidence for semantic interference with distractor words and distractor sounds. These commonalities suggest that semantic interference is a general phenomenon which is not determined by target or distractor modality or their combination (with the exception of word-word interference, e.g., Roelofs, Piai, & Schriefers, 2013). The assumption of competitive lexical selection provides a common framework to account for semantic interference from distractor words, pictures, and sounds alike. Under this account, semantic interference should

arise if semantic-lexical representations of semantically related distractor stimuli receive more activation than unrelated distractor representations. This principle is not affected by distractor or target modality and can therefore be applied to semantic interference with distractor words and pictures in picture and sound naming alike.

To account for semantic interference effects across task configurations in one coherent framework is more challenging for current non-competitive accounts. The most prominent non-competitive account of semantic interference (the response-exclusion hypothesis) was specifically proposed to account for semantic interference from distractor words. It attributes semantic interference to a semantic conflict in a post-lexical articulatory response buffer. It critically relies on the assumption that the distractor word in the context of a word production task is automatically prepared for articulation and transferred into an articulatory response buffer faster than the target picture (Finkbeiner & Caramazza, 2006; Mahon et al., 2007). Because sounds are named slower than pictures (similar to picture naming being slower than word reading), this idea could, in principle, be applied to our task configuration as well if one assumes that an articulatory response to a picture is automatically generated in much the same way as to a word. However, this account can then not simultaneously be applied to semantic interference from distractor sounds in picture naming (Mädebach et al., 2017, Mädebach, Kieseler, & Jescheniak, 2018), that is, in a situation in which an articulatory response to the target can be prepared faster than an articulatory response to distractors.

Perhaps a more promising approach to reconcile the present (and related) findings with the idea of a non-competitive lexical selection mechanism is to assume that the speed of lexical selection is modulated by control mechanisms which adapt selection thresholds when potential conflicts (e.g., increased likelihood to make an error) are detected (Nozari, Dell, & Schwartz, 2011). According to this account,

lexical selection is not principally slowed down by the co-activation of alternative lexical representations. Only if the co-activation is high enough, a conflict monitoring mechanism is triggered which then adjust the thresholds for target selection according to the amount of detected conflict (Nozari & Hepner, 2018). This mechanism is, however, functionally very similar to present competitive selection accounts which assume a competition threshold which restricts competition to representations whose activation surpasses this threshold (La Heij, Boelens, & Kuipers, 2010; Piai, Roelofs, & Schriefers, 2012). In other words, present versions of competitive and non-competitive models converge on the assumption that selection processes are affected by the co-activation of other representations if this co-activation is sufficiently high. The present data are compatible with both the competitive and the non-competitive version of this assumption.

In the present study, distractors were always part of the response set (i.e., they corresponded to a target sound in the experiment). It is likely that this feature of the experimental design promoted the emergence of semantic interference effects. In a picture naming study with distractor sounds we had only observed semantic interference for distractor sounds which corresponded to target pictures in the experiment (Mädebach et al., 2017, Exp. 4). Some early picture-word interference studies likewise suggested that semantic interference may be restricted to distractor words from the response set and consequently it was proposed that lexical competition may be restricted to members of the response set (Roelofs, 1992). However, there is by now ample evidence that response-set membership is not a strict prerequisite for semantic interference from distractor words, especially if the response set is relatively large (for discussion see Caramazza & Costa, 2001; Roelofs, 2001). A recent meta-analysis suggested that semantic interference effects from distractor words are larger and hence more likely to be observed if distractor

words are included in the response set (Forthmann, Bölte, Stauch, & Michel, 2018). Therefore, in the picture-word interference task, the influence of response-set membership might be more gradual than discrete. Whether this is also the case for distractor pictures in sound naming or whether in this or similar task configurations response-set membership is indeed a strict prerequisite for semantic interference is an open question.

On a theoretical level, influences of response-set membership on the size or emergence of semantic interference highlight that semantic relatedness appears to be not the only factor determining semantic interference effects. As we mentioned above, recent versions of competitive selection accounts proposed that competition is restricted to representations which surpass a competition threshold (La Heij et al., 2010; Piai et al., 2012). Assuming that representations which are part of the response set receive more activation and are thus more likely to surpass a competition threshold may explain the response-set effects reported in the literature. The non-competitive response-exclusion account proposed that response relevance of distractor words not semantic relatedness per se is determining whether semantic interference is observed. The present data do not speak to this aspect of the response-exclusion account. In the present experiments, the distractor pictures can surely be considered to be response relevant because they pertained to potential responses in the experiment. Furthermore, the distractor pictures had arguably a stronger association to the object names of the response set than the target sounds which might have made them particularly salient in the sound naming task. This latter aspect may also contribute to the relatively larger semantic interference effects we observed in the present experiments compared to semantic interference effects typically observed in picture-word, picture-sound, and picture-picture interference tasks (e.g., Jescheniak et al., 2014; Mädebach et al., 2017; Schriefers et al., 1990).

In sum, the present results are compatible with the notion that factors like response relevance or response-set membership are important for the emergence of semantic interference effects in addition to semantic relatedness of target and distractor stimulus.

Conclusion

Our experiments demonstrate the feasibility of sound naming tasks for chronometric investigations of semantic processing in general and word production specifically. The results show that, compared to unrelated pictures, congruent pictures facilitate sound identification and semantic-lexical processes involved in name retrieval whereas semantically related pictures interfere with semantic-lexical processes involved in name retrieval. The latter finding contributes to the overall picture that semantic interference in word production is not restricted to target pictures and distractor words but is obtained with quite different target-distractor configurations. Overall, the experiments thus support the view that semantic interference (and congruency facilitation) reflects a general cognitive mechanism involved in word production.

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Disclosure of interest

The authors declare that there is no conflict of interest.

Data availability statement

The data and commented analysis scripts to reproduce the results presented in this article are openly available via the Open Science Framework at <https://osf.io/wqbma/>.

Appendix

Target sounds and distractor pictures separated by distractor condition

target sound	distractor picture			
	congruent	semantic	unrelated	catch/filler
CHATTER _{monkey}	Affe [monkey]	Kuh [cow]	Gitarre [guitar]	Flöte [flute]
HONKING _{car}	Auto [car]	Fahrrad [bicycle]	Schaf [sheep]	Löwe [lion]
SWEEPING _{broom}	Besen [broom]	Staubsauger [hoover]	Auto [car]	Kuh [cow]
DRILLING _{drill}	Bohrer [electric drill]	Hammer [hammer]	Trompete [trumpet]	Dudelsack [bagpipe]
SKIRLING _{bagpipe}	Dudelsack [bagpipe]	Trompete [trumpet]	Pferd [horse]	Staubsauger [hoover]
TRUMPETING _{elephant}	Elefant [elephant]	Schwein [pig]	Bohrer [electric drill]	Fahrrad [bicycle]
QUAKING _{duck}	Ente [duck]	Hahn [rooster]	Orgel [pipe organ]	Klingel [doorbell]
BRAYING _{donkey}	Esel [donkey]	Schaf [sheep]	Hammer [hammer]	Geige [violin]
RINGING _{bicycle}	Fahrrad [bicycle]	Auto [car]	Löwe [lion]	Schaf [sheep]
FLUTESOUND _{flute}	Flöte [flute]	Harfe [harp]	Besen [broom]	Ente [duck]
VIOLINSOUND _{violin}	Geige [violin]	Orgel [pipe organ]	Katze [cat]	Hund [dog]
GUITARSOUND _{guitar}	Gitarre [guitar]	Trommel [drum]	Säge [saw]	Elefant [elephant]
CHIMING _{bell}	Glocke [bell]	Klingel [doorbell]	Schwein [pig]	Schere [scissors]
CROWING _{rooster}	Hahn [rooster]	Ente [duck]	Klingel [doorbell]	Orgel [pipe organ]
HAMMERING _{hammer}	Hammer [hammer]	Bohrer [electric drill]	Dudelsack [bagpipe]	Trompete [trumpet]
HARPSOUND _{harp}	Harfe [harp]	Flöte [flute]	Ente [duck]	Besen [broom]
BARKING _{dog}	Hund [dog]	Pferd [horse]	Zug [train]	Trommel [drum]
MEOWING _{cat}	Katze [cat]	Löwe [lion]	Schiff [ship]	Glocke [bell]
RINGING _{doorbell}	Klingel [doorbell]	Glocke [bell]	Schere [scissors]	Schwein [pig]
MOOING _{cow}	Kuh [cow]	Affe [monkey]	Flöte [flute]	Gitarre [guitar]
ROARING _{lion}	Löwe [lion]	Katze [cat]	Glocke [bell]	Schiff [ship]
ORGANSOUND _{organ}	Orgel [pipe organ]	Geige [violin]	Hund [dog]	Katze [cat]
NEIGHING _{horse}	Pferd [horse]	Hund [dog]	Trommel [drum]	Zug [train]

(Appendix continued)

target sound	distractor picture			
	congruent	semantic	unrelated	catch/filler
SAWING _{saw}	Säge [saw]	Schere [scissors]	Hahn [rooster]	Affe [monkey]
BLEATING _{sheep}	Schaf [sheep]	Esel [donkey]	Geige [violin]	Hammer [hammer]
CUTTING _{scissors}	Schere [scissors]	Säge [saw]	Affe [monkey]	Hahn [rooster]
HORN _{ship}	Schiff [ship]	Zug [train]	Harfe [harp]	Esel [donkey]
GRUNTING _{pig}	Schwein [pig]	Elefant [elephant]	Fahrrad [bicycle]	Bohrer [electric drill]
HOOVERING _{hoover}	Staubsauger [hoover]	Besen [broom]	Kuh [cow]	Auto [car]
DRUMMING _{drum}	Trommel [drum]	Gitarre [guitar]	Elefant [elephant]	Säge [saw]
TRUMPETING _{trumpet}	Trompete [trumpet]	Dudelsack [bagpipe]	Staubsauger [hoover]	Pferd [horse]
HORN _{train}	Zug [train]	Schiff [ship]	Esel [donkey]	Harfe [harp]

Note. English translations are given in brackets.

References

- Abdel Rahman, R. & Melinger, A. (2009). Semantic context effects in language production. A swinging lexical network proposal and a review. *Language and Cognitive Processes*, 24, 713–734. <https://doi.org/10.1080/01690960802597250>
- Abdel Rahman, R., & Melinger, A. (2019). Semantic processing during language production: An update of the swinging lexical network. *Language, Cognition and Neuroscience*, 34, 1176–1192.
- Alario, F.-X., Segui, J. & Ferrand, L. (2000). Semantic and associative priming in picture naming. *The Quarterly Journal of Experimental Psychology: Section A*, 53, 741–764. <https://doi.org/10.1080/027249800410535>
- Aristei, S., Zwitserlood, P. & Abdel Rahman, R. (2012). Picture-induced semantic interference reflects lexical competition during object naming. *Frontiers in Psychology*, 3. <https://doi.org/10.3389/fpsyg.2012.00028>
- Baayen, R. H., Davidson, D., & Bates, D. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, 59, 390–412.
- Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, 68, 255–278.
- Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67.
- Belke, E. (2013). Long-lasting inhibitory semantic context effects on object naming are necessarily conceptually mediated: Implications for models of lexical-semantic encoding. *Journal of Memory and Language*, 69, 228–256.
- Bloem, I. & La Heij, W. (2003). Semantic facilitation and semantic interference in word translation. Implications for models of lexical access in language production. *Journal of Memory and Language*, 48, 468–488. [https://doi.org/10.1016/S0749-596X\(02\)00503-X](https://doi.org/10.1016/S0749-596X(02)00503-X)
- Caramazza, A., & Costa, A. (2001). Set size and repetition in the picture–word interference paradigm: Implications for models of naming. *Cognition*, 80, 291–298.
- Cattell, J. M. (1886). The time it takes to see and name objects. *Mind*, 11, 63–65.
- Chen, Y.-C. & Spence, C. (2010). When hearing the bark helps to identify the dog: semantically-congruent sounds modulate the identification of masked pictures. *Cognition*, 114, 389–404. <https://doi.org/10.1016/j.cognition.2009.10.012>
- Chen, Y.-C. & Spence, C. (2011). Crossmodal semantic priming by naturalistic sounds and spoken words enhances visual sensitivity. *Journal of Experimental Psychology: Human Perception and Performance*, 37, 1554–1568. <https://doi.org/10.1037/a0024329>
- Chen, Y.-C. & Spence, C. (2018). Audiovisual semantic interactions between linguistic and nonlinguistic stimuli. The time-courses and categorical specificity. *Journal of Experimental Psychology: Human Perception and Performance*, 44, 1488–1507. <https://doi.org/10.1037/xhp0000545>

- Damian, M. F. & Bowers, J. S. (2003). Locus of semantic interference in picture-word interference tasks. *Psychonomic Bulletin & Review*, 10, 111–117. <https://doi.org/10.3758/BF03196474>
- Damian, M. F. & Martin, R. C. (1999). Semantic and phonological codes interact in single word production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 25, 345–361. <https://doi.org/10.1037/0278-7393.25.2.345>
- Dell'Acqua, R., Job, R., Peressotti, F. & Pascali, A. (2007). The picture-word interference effect is not a Stroop effect. *Psychonomic Bulletin & Review*, 14, 717–722. <https://doi.org/10.3758/BF03196827>
- 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. <https://doi.org/10.1037/a0019128>
- Finkbeiner, M. & Caramazza, A. (2006). Now you see it, now you don't: On turning semantic interference into facilitation in a Stroop-like task. *Cortex*, 42, 790–796. [https://doi.org/10.1016/S0010-9452\(08\)70419-2](https://doi.org/10.1016/S0010-9452(08)70419-2)
- Forthmann, B., Bölte, J., Strauch, B., & Michel, R. (2018). Interference Prevails? A quantitative research synthesis of the picture-word-interference paradigm. *Poster presented at the 10th International Workshop on Language Production*, Nijmegen, Netherlands.
- Geng, J., Kirchgessner, M. & Schnur, T. T. (2013). The mechanism underlying lexical selection: evidence from the picture-picture interference paradigm. *The Quarterly Journal of Experimental Psychology*, 66, 261–276. <https://doi.org/10.1080/17470218.2012.705861>
- Glaser, W. R. (1992). Picture naming. *Cognition*, 42, 61–105.
- Glaser, W. R. & Döngelhoff, F. J. (1984). The time course of picture-word interference. *Journal of Experimental Psychology: Human Perception and Performance*, 10, 640–654. <https://doi.org/10.1037/0096-1523.10.5.640>
- <https://doi.org/10.1037/0096-3445.118.1.13>
- Hantsch, A., Jescheniak, J. D. & Schriefers, H. (2009). Distractor modality can turn semantic interference into semantic facilitation in the picture-word interference task: implications for theories of lexical access in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 35, 1443–1453. <https://doi.org/10.1037/a0017020>
- Hocking, J., Dzafic, I., Kazovsky, M. & Copland, D. A. (2013). NESSTI: norms for environmental sound stimuli. *PLoS ONE*, 8, e73382. <https://doi.org/10.1371/journal.pone.0073382>
- Hommel, B. (1998). Automatic stimulus-response translation in dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 1368–1384. <https://doi.org/10.1037/0096-1523.24.5.1368>
- Humphreys, G. W., Riddoch, M. J., & Quinlan, P. T. (1988). Cascade processes in picture identification. *Cognitive Neuropsychology*, 5, 67–104.
- Indefrey, P. (2011). The spatial and temporal signatures of word production components. A critical update. *Frontiers in Psychology*, 2, 255. <https://doi.org/10.3389/fpsyg.2011.00255>

- Iordanescu, L., Guzman-Martinez, E., Grabowecky, M., & Suzuki, S. (2008). Characteristic sounds facilitate visual search. *Psychonomic Bulletin & Review*, 15, 548–554.
- Iordanescu, L., Grabowecky, M., Franconeri, S., Theeuwes, J. & Suzuki, S. (2010). Characteristic sounds make you look at target objects more quickly. *Attention, Perception, & Psychophysics*, 72, 1736–1741. <https://doi.org/10.3758/APP.72.7.1736>
- Jescheniak, J. D., Matushanskaya, A., Mädebach, A. & Müller, M. M. (2014). Semantic interference from distractor pictures in single-picture naming: evidence for competitive lexical selection. *Psychonomic Bulletin & Review*, 21, 1294–1300. <https://doi.org/10.3758/s13423-014-0606-5>
- Jescheniak, J. D., Oppermann, F., Hantsch, A., Wagner, V., Mädebach, A. & Schriefers, H. (2009). Do perceived context pictures automatically activate their phonological code? *Experimental Psychology*, 56, 56–65. <https://doi.org/10.1027/1618-3169.56.1.56>
- Kung, E. & Hamm, J. P. (2010). A model of rotated mirror/normal letter discriminations. *Memory & Cognition*, 38, 206–220. <https://doi.org/10.3758/MC.38.2.206>
- Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package: Tests in linear mixed effects models. *Journal of Statistical Software*, 82.
- Kvasova, D., Garcia-Vernet, L., & Soto-Faraco, S. (2019). Characteristic sounds facilitate object search in real-life scenes. *Frontiers in Psychology*, 10.
- La Heij, W., Boelens, H. & Kuipers, J.-R. (2010). Object interference in children's colour and position naming: Lexical interference or task-set competition? *Language and Cognitive Processes*, 25, 568–588. <https://doi.org/10.1080/01690960903381174>
- La Heij, W., Heikoop, K. W., Akerboom, S. & Bloem, I. (2003). Picture naming in picture context: Semantic interference or semantic facilitation? *Psychology Science*, 45, 49–62.
- La Heij, W., Kuipers, J.-R. & Starreveld, P. A. (2006). In defense of the lexical-competition account of picture-word interference. A comment on Finkbeiner and Caramazza (2006). *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, 42, 1028–1031. [https://doi.org/10.1016/S0010-9452\(08\)70209-0](https://doi.org/10.1016/S0010-9452(08)70209-0)
- La Heij, W., Starreveld, P. A. & Steehouwer, L. C. (1993). Semantic interference and orthographic facilitation in definition naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 19, 352–368. <https://doi.org/10.1037/0278-7393.19.2.352>
- Lambon Ralph, M. A. (2014). Neurocognitive insights on conceptual knowledge and its breakdown. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 369, 20120392. <https://cran.r-project.org/web/packages/ez/index.html>
- Levelt, W. J. M., Roelofs, A. & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22, 1–75. <https://doi.org/10.1017/S0140525X99001776>

- Logan, G. D. & Schulkind, M. D. (2000). Parallel memory retrieval in dual-task situations. I. Semantic memory. *Journal of Experimental Psychology: Human Perception and Performance*, 26, 1072–1090. <https://doi.org/10.1037/0096-1523.26.3.1072>
- Lupker, S. J. (1979). The semantic nature of response competition in the picture-word interference task. *Memory & Cognition*, 7, 485–495. <https://doi.org/10.3758/BF03198265>
- Mädebach, A., Kieseler, M.-L. & Jescheniak, J. D. (2018). Localizing semantic interference from distractor sounds in picture naming: A dual-task study. *Psychonomic Bulletin & Review*, 25, 1909–1916. <https://doi.org/10.3758/s13423-017-1386-5>
- Mädebach, A., Wöhner, S., Kieseler, M.-L. & Jescheniak, J. D. (2017). Neighing, barking, and drumming horses - Object related sounds help and hinder picture naming. *Journal of Experimental Psychology: Human Perception and Performance*, 43, 1629–1646. <https://doi.org/10.1037/xhp0000415>
- Mädebach, A., Wöhner, S., & Jescheniak, J. D. (2018). Opening a file drawer – Surprisingly consistent evidence for semantic interference from distractor pictures in picture naming. *Poster presented at the 10th International Workshop on Language Production*, Nijmegen, Netherlands. <https://osf.io/sk62t/>
- Mahon, B. Z. & Caramazza, A. (2009). Why does lexical selection have to be so hard? Comment on Abdel Rahman and Melinger's swinging lexical network proposal. *Language and Cognitive Processes*, 24, 735–748. <https://doi.org/10.1080/01690960802597276>
- Mahon, B. Z., Costa, A., Peterson, R., Vargas, K. A. & 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. <https://doi.org/10.1037/0278-7393.33.3.503>
- Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature*, 379, 649–652.
- Matushanskaya, A., Mädebach, A., Müller, M. M. & Jescheniak, J. D. (2016). When sufficiently processed, semantically related distractor pictures hamper picture naming. *Experimental Psychology*, 63, 307–317. <https://doi.org/10.1027/1618-3169/a000340>
- Milivojevic, B., Hamm, J. P. & Corballis, M. C. (2011). About turn. How object orientation affects categorisation and mental rotation. *Neuropsychologia*, 49, 3758–3767. <https://doi.org/10.1016/j.neuropsychologia.2011.09.034>
- Miller, J. (2006). Backward crosstalk effects in psychological refractory period paradigms. Effects of second-task response types on first-task response latencies. *Psychological Research*, 70, 484–493. <https://doi.org/10.1007/s00426-005-0011-9>
- Miller, J. & Alderton, M. (2006). Backward response-level crosstalk in the psychological refractory period paradigm. *Journal of Experimental Psychology:*

- Human Perception and Performance*, 32, 149–165. <https://doi.org/10.1037/0096-1523.32.1.149>
- <http://cran.r-project.org/web/packages/BayesFactor/index.html>
- Mulatti, C. & Coltheart, M. (2012). Picture-word interference and the response-exclusion hypothesis. *Cortex*, 48, 363–372. <https://doi.org/10.1016/j.cortex.2011.04.025>
- Navarrete, E. & Mahon, B. Z. (2013). A rose by any other name is still a rose. A reinterpretation of Hantsch and Mädebach. *Language and Cognitive Processes*, 28, 701–716. <https://doi.org/10.1080/01690965.2012.682071>
- Nozari, N., Dell, G. S. & Schwartz, M. F. (2011). Is comprehension necessary for error detection? A conflict-based account of monitoring in speech production. *Cognitive Psychology*, 63, 1–33. <https://doi.org/10.1016/j.cogpsych.2011.05.001>
- Nozari, N. & Hepner, C. R. (2018). To select or to wait? The importance of criterion setting in debates of competitive lexical selection. *Cognitive Neuropsychology*, 1–15. <https://doi.org/10.1080/02643294.2018.1476335>
- Nunez-Pena, M. I. & Aznar-Casanova, J. A. (2009). Mental rotation of mirrored letters. Evidence from event-related brain potentials. *Brain and Cognition*, 69, 180–187. <https://doi.org/10.1016/j.bandc.2008.07.003>
- Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin*, 116, 220–244. <https://doi.org/10.1037//0033-2909.116.2.220>
- Pashler, H., & Johnston, J. C. (1989). Chronometric evidence for central postponement in temporally overlapping tasks. *The Quarterly Journal of Experimental Psychology*, 41, 19–45.
- Piai, V., Roelofs, A. & Roete, I. (2015). Semantic interference in picture naming during dual-task performance does not vary with reading ability. *The Quarterly Journal of Experimental Psychology*, 68, 1758–1768. <https://doi.org/10.1080/17470218.2014.985689>
- Piai, V., Roelofs, A., & Schriefers, H. (2012). Distractor strength and selective attention in picture-naming performance. *Memory & Cognition*, 40, 614–627. <https://doi.org/10.1016/j.jml.2011.01.004>
- Piai, V., Roelofs, A. & Schriefers, H. (2014). Locus of semantic interference in picture naming: Evidence from dual-task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40, 147–165. <https://doi.org/10.1037/a0033745>
- R Core Team. (2019). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. <http://www.R-project.org/>
- Roelofs, A. (1992). A spreading-activation theory of lemma retrieval in speaking. *Cognition*, 42, 107–142. [https://doi.org/10.1016/0010-0277\(92\)90041-F](https://doi.org/10.1016/0010-0277(92)90041-F)
- Roelofs, A. (2001). Set size and repetition matter: Comment on Caramazza and Costa (2000). *Cognition*, 80, 283–290.

- Roelofs, A. (2008). Tracing attention and the activation flow of spoken word planning using eye movements. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34, 353–368. <https://doi.org/10.1037/0278-7393.34.2.353>
- Roelofs, A. (2018). A unified computational account of cumulative semantic, semantic blocking, and semantic distractor effects in picture naming. *Cognition*, 172, 59–72. <https://doi.org/10.1016/j.cognition.2017.12.007>
- Roelofs, A., & Piai, V. (2013). Associative facilitation in the Stroop task: Comment on Mahon et al. (2012). *Cortex*, 49, 1767–1769. <https://doi.org/10.1016/j.cortex.2013.03.001>
- Roelofs, A., Piai, V. & Schriefers, H. (2013). Selection by competition in word production. Rejoinder to Janssen (2013). *Language and Cognitive Processes*, 28, 679–683. <https://doi.org/10.1080/01690965.2013.770890>
- Schneider, T. R., Engel, A. K., & Debener, S. (2008). Multisensory identification of natural objects in a two-way crossmodal priming paradigm. *Experimental Psychology*, 55, 121–132. Schnur, T. T. & Martin, R. C. (2012). Semantic picture-word interference is a postperceptual effect. *Psychonomic Bulletin & Review*, 19, 301–308. <https://doi.org/10.3758/s13423-011-0190-x>
- Schriefers, H., Meyer, A. S. & Levelt, W. J. M. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language*, 29, 86–102. [https://doi.org/10.1016/0749-596X\(90\)90011-N](https://doi.org/10.1016/0749-596X(90)90011-N)
- Spalek, K., Damian, M. F. & Bölte, J. (2013). Is lexical selection in spoken word production competitive? Introduction to the special issue on lexical competition in language production. *Language and Cognitive Processes*, 28, 597–614. <https://doi.org/10.1080/01690965.2012.718088>
- Starreveld, P. A. & La Heij, W. (1995). Semantic interference, orthographic facilitation, and their interaction in naming tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21, 686–698. <https://doi.org/10.1037/0278-7393.21.3.686>
- Telford, C. W. (1931). The refractory phase of voluntary and associative responses. *Journal of Experimental Psychology*, 14, 1–36. <https://doi.org/10.1037/h0073262>
- Theios, J., & Amrhein, P. C. (1989). Theoretical analysis of the cognitive processing of lexical and pictorial stimuli: Reading, naming, and visual and conceptual comparisons. *Psychological Review*, 96, 5–24.
- Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature*, 381, 520–522. Tombu, M. & Jolicœur, P. (2003). A central capacity sharing model of dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance*, 29, 3–18. <https://doi.org/10.1037/0096-1523.29.1.3>
- Uddin, S., Heald, S. L. M., van Hedger, S. C., Klos, S. & Nusbaum, H. C. (2018). Understanding environmental sounds in sentence context. *Cognition*, 172, 134–143. <https://doi.org/10.1016/j.cognition.2017.12.009>

- Van Casteren, M. & Davis, M. H. (2006). Mix, a program for pseudorandomization. *Behavior Research Methods*, 38, 584–589. <https://doi.org/10.3758/BF03193889>
- Van Maanen, L., van Rijn, H. & Borst, J. P. (2009). Stroop and picture-word interference are two sides of the same coin. *Psychonomic Bulletin & Review*, 16, 987–999. <https://doi.org/10.3758/PBR.16.6.987>
- Vigliocco, G., Vinson, D. P., Lewis, W., & Garrett, M. F. (2004). Representing the meanings of object and action words: The featural and unitary semantic space hypothesis. *Cognitive Psychology*, 48, 422–488.
- Wagenmakers, E.-J. (2007). A practical solution to the pervasive problems of p values. *Psychonomic Bulletin & Review*, 14, 779–804.
- Yuval-Greenberg, S. & Deouell, L. Y. (2009). The dog's meow. Asymmetrical interaction in cross-modal object recognition. *Experimental Brain Research*, 193, 603–614. <https://doi.org/10.1007/s00221-008-1664-6>