**Naming Pictures and Sounds:
Stimulus Type Affects Semantic Context Effects**

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Abstract

Semantic context effects obtained in naming tasks have been most influential in devising and evaluating models of word production. We re-investigated this effect in the frequently used blocked-cyclic naming task in which stimuli are presented repeatedly either sorted by semantic category (homogeneous context) or intermixed (heterogeneous context). Previous blocked-cyclic naming studies have shown slower picture naming responses in the homogeneous context. Our study compared this context effect in two task versions, picture naming and sound naming. Target words were identical across task versions (e.g., participants responded with the word “dog” to either the picture of that animal or to the sound [barking] produced by it). We found semantic interference in the homogeneous context also with sounds and the effect was substantially larger than with pictures (Experiments 1 and 2). This difference is unlikely to result from extended perceptual processing of sounds as compared to pictures (Experiments 3 and 4) or from stronger links between pictures and object names than between sounds and object names (Experiment 5). Overall, our results show that semantic context effects in blocked-cyclic naming generalize to stimulus types other than pictures and – in part – also reflect pre-lexical processes that depend on the nature of the stimuli used for eliciting the naming responses. This highlights the need to consider the impact of initial processing steps in naming studies when devising and evaluating theories of word production.

Public significance statement

Theories of word production often rely on evidence from picture naming. The present study contrasts sound and picture naming (naming a barking sound vs. a picture of a dog). The results suggest that initial, stimulus-specific processes modulate observations previously ascribed to stimulus-unspecific word production processes. This highlights the need to consider the impact of initial processing steps in naming studies when devising and evaluating theories of word production.

Keywords: speech production, word production, lexical access, semantic context effects, blocked-cyclic naming, picture naming, sound naming

Word production is an integral part of communication, but has been studied far less extensively than word comprehension. One reason are inherent difficulties in devising techniques that allow for rigid experimental control of input (i.e., communicative intention) and output (i.e., verbal response, Bock, 1996). Picture naming is one of the few tools that meets this requirement. Consequently, evidence from picture naming studies has been widely used to inform word production models and many hallmark findings in picture naming have been attributed to general word production mechanisms. However, in many cases it is not known whether these findings would generalize to other word production tasks. In particular, it is usually not known which role initial processing steps specific to picture naming may play for phenomena supposedly reflecting genuine, stimulus-unspecific word production processes. In this article, we present a series of word production experiments which demonstrate that stimulus-specific lead-in processes influence results in a way which is not explained by current word production models. We focus on one frequently used task, the blocked-cyclic naming task, and on one central phenomenon observed with it, semantic interference. We contrasted two task versions, the standard picture-naming version and a novel sound-naming version. We asked (a) whether the key finding of the picture-naming task version, semantic interference that arises when pictures are presented repeatedly blocked by semantic category, is obtained with the sound-naming task version as well and if so (b) whether it shows comparable characteristics.

Semantic Interference in Blocked-Cyclic Picture Naming

In the blocked-cyclic naming task, small sets of typically four or five pictures that come either from the same semantic category (homogenous context) or from different semantic categories (heterogeneous context) are named repeatedly over a

number of so-called cycles (in which all pictures of the set are named once). It is consistently found that naming responses are slower in the homogeneous context than in the heterogeneous context, typically from the second cycle onwards (Abdel Rahman & Melinger, 2007; Belke et al., 2005; Damian & Als, 2005; Damian et al., 2001).

Several studies have explored the nature of this semantic interference effect. Kroll and Stewart (1994) observed semantic interference in picture naming but not in word naming, ruling out access to phonology and articulation as origin and locus of the effect¹. Damian et al. (2001) replicated the interference effect in picture naming but found no effect in picture orientation judgment, in which participants decided via a manual response whether the front of an object (e.g., the nose of a mouse) pointed to the left or to the right. The absence of interference in this semantic task was taken as evidence that the effect in picture naming does not originate at the conceptual level but at a later (lexical) stage; otherwise it should have become visible in orientation judgment as well. In a further experiment, the pictures were replaced with corresponding words and participants were asked to respond by producing definite determiner-noun phrases or bare nouns. In German, the language in which the experiment was carried out, the definite determiner form depends on the grammatical gender of the noun; this information is assumed to be accessed via the noun's abstract lexical representation (e.g., Levelt et al., 1999). Therefore, determiner-noun naming, unlike bare noun naming, requires selection of the abstract lexical representation. Damian et al. (2001) obtained semantic interference in determiner-noun naming but not in bare noun naming which invited the conclusion that semantic

¹ This study, in contrast to subsequent ones, presented each stimulus to a given participant only once, either in the homogeneous context or in the heterogeneous context. Thus, strictly speaking, Kroll and Stewart (1994) used a blocked naming task, not a blocked-cyclic naming task.

interference in blocked-cyclic naming originates at the abstract lexical level and has its locus at that level, too.

Belke (2013) criticized this conclusion. First, she questioned whether the semantic (orientation judgment) task indeed involves similar conceptual processing as picture naming. To carry out the orientation judgment, access to structural object representations without elaborated semantic processing might suffice (Humphreys et al., 1988; 1995). Second, Belke failed to replicate semantic interference in determiner-noun naming (Belke, 2013, Experiment 3), questioning the assumption that the effect is to be attributed to lexical processing. Moreover, when semantic picture classification (living vs. non-living) and picture naming were combined, Belke found facilitation in semantic classification and interference in naming. The presence of facilitation in semantic classification suggests that the conceptual level is involved in but cannot be the locus of interference found in picture naming. Belke suggested that the overall pattern of results is best explained by assuming that semantic interference in blocked-cyclic picture naming has a conceptual origin and lexical locus at which it eventually takes effect (see also Belke et al., 2005).

Two recent computational word production models are in line with this notion. In Oppenheim et al.'s model (2010), the origin of the effect is assumed to be at the interface of the conceptual and the lexical level, implemented by long-lasting incremental weight adjustments of the semantic feature-to-lexical node connections, which occur after each naming episode. The locus of the effect, however, is assumed to be at the lexical level during (non-competitive) target-word selection. In Roelofs' model (2018) the origin of the effect is assumed to be at the conceptual level, implemented in terms of a short-lived conceptual bias, and its locus at the lexical level during (competitive) target-word selection. In summary, despite a number of controversial issues in detail (e.g., whether the origin is at the conceptual level proper

or at the interface of the conceptual and lexical level), there seems to be some consensus that both conceptual and lexical levels are involved in semantic interference in the blocked-cyclic naming task.

Beyond Blocked-Cyclic Picture Naming

The blocked-cyclic naming task is widely used and has been highly influential in the development and evaluation of current word production models (e.g., Howard et al., 2006; Oppenheim et al., 2010). Interestingly, though, so far blocked-cyclic naming studies have almost exclusively used pictures as target stimuli and only occasionally written words. Moreover, words have only been used to identify the boundary conditions under which semantic interference is obtained. As stated earlier, it is usually not known which role initial processing steps specific to picture naming may play for observations supposedly reflecting genuine, stimulus-unspecific word production processes. Specifically, when it comes to exploring semantic-lexical processes in word production, the particular choice of a stimulus type used for triggering the production process should not matter, as long as it activates a specific semantic representation which then triggers the lexical retrieval process. The use of pictures of objects is mostly done for convenience, as they do so with high precision. At the same time, these picture stimuli introduce stimulus-specific lead-in processes (Indefrey & Levelt, 2004; Levelt et al., 1999) such as perceptual and structural analysis and object classification that are not part of the core processes involved in everyday word production outside the laboratory. One strategy for separating (uninformative yet unavoidable) effects of stimulus-specific lead-in processes from (informative) effects of core processes in word production is to test whether similar patterns of results are obtained when other stimuli are used that differ in lead-in but not in core processes. One promising type of such stimuli are environmental sounds (e.g., barking, hammering, honking). Recent evidence suggests that such sounds are

suitable for word production research (Mädebach et al., 2017, 2018; Wöhner et al., 2020). The aim of the present study was to test (a) whether semantic interference in the blocked-cyclic naming task is also obtained with sounds and (b) whether any such effect has the same properties as the corresponding effect obtained with pictures.

Pictures, Sounds, and Semantic Representations

Word production models incorporate semantic features at the conceptual level that are either directly connected to abstract lexical representations (e.g., Oppenheim et al., 2007) or are connected to holistic (lexical) concepts which are then connected to abstract lexical representations (e.g., Belke, 2013; Levelt et al., 1999; Roelofs, 2018; Vigliocco et al., 2004). For example, perceptual features like “furry”, “four-footed”, “barks” may either be connected directly to the word “dog” or indirectly via the concept “dog”. Although to date our knowledge about how environmental sounds are processed and named is still limited (Hocking et al., 2013; Uddin et al., 2018), it is reasonable to assume that in the context of current models environmental sounds activate one or more perceptual features in a similar way as pictures do and that these features then (directly or indirectly) activate abstract lexical representations. Still, there are also differences between picture and sound processing that might affect task performance. First, for a sound the physical signal has to unfold over some time before sufficient perceptual information is available for conceptual identification. In contrast, for a picture all perceptual information is available instantly, leading to more rapid conceptual access (for reviews see Murray & Spierer, 2009; Potter, 2014). Second, there might be a higher uncertainty in the mapping of a sound onto a unique concept or name. For instance, some sounds might be labeled according to their source (e.g., car), their more concrete source (e.g., car horn), or

the action producing the sound (e.g., honking)². Third, sound naming is likely a less overlearned task than picture naming. Fourth, sound stimuli might be perceptually less distinct within semantic categories than picture stimuli. Fifth, the temporal dynamic of semantic activation might differ between pictures and sounds, for instance with regard to the progression from vague to more specific semantic information (coarse-to-fine processing, see Murray & Spierer, 2009). We return to these issues in the General Discussion. Each of these aspects could contribute to slower sound naming than picture naming. In fact, using the same set of target words we observed sizeable latency differences in sound naming (above 1,000 ms; Wöhner et al., 2020) and picture naming (below 700 ms; Mädebach et al., 2017) in previous studies.

It is far from clear, however, whether semantic interference in blocked-cyclic naming would differ for sounds and pictures. If semantic interference arises after conceptual preparation, that is after the lexical concept or the set of semantic features of a target word has been identified (Levelt et al., 1999), the effect should be comparable in sound and picture naming. In contrast, if earlier perceptual or semantic processes contribute to the effect, it might differ in sound and picture naming. Hence, any difference versus similarity of semantic interference in blocked-cyclic picture and sound naming can provide further information about the origin and locus of an effect, which is critical for theorizing about word production.

Outline of the Present Study

We present a series of blocked-cyclic naming experiments that systematically varied the stimulus type (picture vs. sound) while keeping all other factors constant. In Experiment 1, participants either named pictures (e.g., *horse*, *dog*, *guitar*, *drum*) or

² This is not to say that the mapping of pictures onto concepts or names is achieved without any uncertainty (see Brown, 1958).

sounds associated with the depicted objects (e.g., *barking*_{dog}, *neighing*_{horse}, *guitarsound*_{guitar}, *drumming*_{drum}) by producing the object names (e.g., “horse”, “dog”, “guitar”, “drum”). We expected to observe semantic interference with pictures, that is slower responses when stimuli are blocked by semantic category (homogeneous context) than when they are intermixed (heterogeneous context), replicating a core finding from the literature and providing an estimate of the effect for our experimental materials. The critical question was whether the effect would replicate with sounds. We predicted this to be the case if the effect reflects core processes of conceptually driven word production rather than some stimulus-specific lead in-processes. Moreover, if the effect arises once conceptual preparation has been completed, we predicted it to be of similar size for the two stimulus types (when possible differences in naming performance between task versions are taken into account), because all later processes are shared between task versions. To anticipate, the semantic effect was substantially larger with sounds than with pictures. Experiment 2 asked whether the pattern would replicate when pictures and sounds are presented intermixed (e.g., *barking*_{dog}, *horse*, *guitarsound*_{guitar}, *drum*) – it did. Three more experiments explored the possible source of the differently sized effects. Experiments 3 and 4 asked whether the larger semantic effect with sounds could result from prolonged perceptual processing of sounds as compared to pictures. If so, the effect should also be enhanced when perceptual processing of pictures is stretched out in time. Experiment 5 asked whether the larger semantic effect with sounds could result from weaker links between sounds and object names than between pictures and object names. If so, the relative size of the effects with sounds and pictures should differ between object naming (e.g., “dog”, for the reason given) and action naming (e.g., “barking”, because the link between sounds and actions is likely stronger than between pictures and action names).

Sample Size and Power

In all experiments, the participant sample size (tested with a particular stimulus type or response format) was identical and determined in advance on the basis of related studies (and design considerations). In published studies, semantic interference in blocked-cyclic picture naming was repeatedly found with relatively small participant samples ranging from 8 to 20 participants (16 – 25 items, 4 – 12 cycles; Belke, Brysbaert et al., 2005; Belke, Meyer, & Damian, 2005; Damian et al., 2001; Damian & Als, 2005; Maess et al., 2002). Because we were interested in possible differences of semantic interference as a function of stimulus type, we opted for a participant sample size at the upper boundary of this range, namely 32 per stimulus type or response format.

We had not conducted an a-priori power analysis, but calculated an estimate of the achieved power to replicate the baseline effect (semantic interference in picture naming) in our experiments. We calculated an estimate of the population effect size based on nine previous studies that tested young adults with a design comparable to the one we used (Abdel Rahman & Melinger, 2007, 2011; Belke, Brysbaert et al., 2005; Belke, Meyer, & Damian, 2005; Damian et al., 2001; Damian & Als, 2005; Maess et al., 2002; Navarrete et al., 2012; Wang et al., 2018). The mean standardized effect across these studies was $d_z = 1.0$, 95% *CI* [0.7; 1.3] in the participant analysis and $d_z = 0.8$, 95% *CI* [0.6; 0.9] in the item analysis (for details of the calculation see <https://osf.io/73btq/>). Each of our experiments ($N = 32$, 16 items) had a power of > 99% (participant analysis) and 85% (item analysis) to observe an effect of that size (in a two-sided test with $\alpha = .05$).

For the novel sound naming task, no previous studies and consequently no independent estimate of the population effect are available. Initially, for Experiment 1,

we predicted a similar effect as in picture naming, which would imply the same power as calculated for picture naming. The main conclusion from our study rests on the interaction between input stimulus (sound vs. picture in Experiments 1, 2, and 5; degraded vs. intact pictures in Experiments 3 and 4) and context (semantically homogeneous vs. heterogeneous). When using the results of Experiment 1 as an estimate for the underlying population effects, Experiments 2 – 5 would have had, unsurprisingly given the similar design and sample sizes, sufficient power to replicate this critical interaction (i.e., > 90%; calculated with the R-package Superpower, Lakens & Caldwell, 2019). This power estimate has to be treated with caution, because the results of Experiment 1 may very well overestimate the population effect size. However, the repeated observation of a substantially larger semantic interference effect in sound naming (Experiments 1, 2, 5) also suggests that the present experiments were sufficiently powered.

We report all data exclusions, all manipulations, and all measures implemented in the experiments. We make available all materials, data, and analysis scripts: <https://osf.io/73btq/>.

Experiment 1

Participants either named pictures (e.g., of a dog) or sounds associated with the depicted objects (e.g., barking) in semantically homogeneous and heterogeneous contexts by producing the names of the objects (e.g., “dog”). For picture naming, we predicted longer naming latencies in the homogeneous context. The critical question was whether a similar effect would be present for sounds.

Method

Participants. We tested 64 participants (51 females, mean age = 23.56 years, range = 18 – 37 years, $SD = 4.43$), most of them students from Leipzig University. Half of them were assigned to the picture naming task and the other half to the sound naming task. One participant was replaced because of technical problems (lab lighting malfunctioning). In all experiments the participants were German native speakers and had normal or corrected to normal vision and no known hearing deficits. Participants gave informed written consent before the experiment started. They either received course credit or were financially reimbursed (8 €). Our study and all its experimental procedures followed the ethical guidelines of the German Psychological Society (DGPs). According to the regulations of the German Research Council (DFG) the kind of research we describe in this paper does not require formal approval from a research ethics committee because (a) our method does not involve any risks or emotional or physical stress (naming of neutral pictures and sounds) and (b) informed consent was obtained from the participants (see http://www.dfg.de/foerderung/faq/geistes_sozialwissenschaften/index.html). None of the participants was tested in more than one of the experiments.

Materials. Picture stimuli were color photographs of 16 common objects (sampled from various sources), four from each of four semantic categories (mammals, vehicles, tools, musical instruments). Pictures filled an imaginary square of 250 pixels x 250 pixels (corresponding to 7.3 cm x 7.3 cm or a visual angle of 7.0° x 7.0° at 60 cm viewing distance) and had their background removed. For each picture, a corresponding sound was selected (e.g., *barking_{dog}* for the picture of a dog). With one exception, the sounds were taken from Mädebach et al. (2017). They ranged from 796 to 1,448 ms ($M = 1,143$ ms, $SD = 218$ ms).

Stimuli were arranged in a 4 x 4 matrix with each line representing the item subsets used for creating a homogeneous block and each row representing the item subsets used for creating a heterogeneous block, see Appendix A. Within each block, the items were repeated eight times, creating eight cycles. Blocks involving items in line_n and row_n were combined into pairs and were always presented in direct succession. The sequence of these pairs was controlled using a sequentially-balanced Latin square design. Homogeneous and heterogeneous blocks alternated. Half of the participants started with a homogeneous block and half with a heterogeneous block.

Apparatus. The experiment was controlled by NESU (MPI for Psycholinguistics). Pictures were presented on a 19" monitor. Sounds were presented with headphones at comfortable listening volume. Naming latencies were measured with a microphone connected to the hardware voice-key.

Design. Stimulus type (pictures vs. sounds) was tested between participants and within items. Context (homogeneous vs. heterogeneous) and cycle (1 – 8) were tested within participants and within items. This resulted in 256 experimental trials per participant. Thirty-two pseudo-randomized presentation lists were created with Mix (Van Casteren & Davis, 2006). The only constraint was that within any (homogeneous or heterogeneous) block identical items were not repeated in direct succession. Each list was once used with picture stimuli and once with sound stimuli.

Procedure. Participants were tested individually. First, participants received written instructions asking them to respond quickly and accurately. They were then familiarized with the experimental materials. For the picture naming task, each picture was presented on the computer screen for 3 secs with its name below it and participants read the name aloud. In a subsequent practice phase, each picture was presented without name and participants named it quickly and accurately. The

experimenter corrected non-target names. For the sound naming task, the pictures were replaced with sounds. After familiarization and practice, all experimental trials were presented with a short break after half of them.

Experimental trials started with a black fixation cross (500 ms) followed by a blank screen (500 ms) and the target picture (1,500 ms) or the target sound (varying from 796 to 1,448 ms). Background color was light grey (RGB 220 220 220), visual stimuli were presented in the center of the screen. Naming latency was measured from target onset for up to 3 secs. Trials lasted 5 secs.

Results and Discussion

Accuracy of responses and voice-key triggers were monitored online by the experimenter. Errors were coded and naming latencies excluded from analysis if there was (a) a non-expected or missing response, (b) a disfluency, or (c) a non-speech sound (smack) by the participant triggering the voice-key (1.90% of all observations). Naming latencies were also excluded if a technical error occurred or the voice-key triggered with a latency of 300 ms or less (1.01%, no error coded in these cases).

Analyses were conducted in R (R Core Team, 2018). Averaged naming latencies and error rates were submitted to ANOVAs involving the variables stimulus type, context, and cycle. We report frequentist analyses, one treating participants and one treating items as random variable. Greenhouse-Geisser corrected degrees of freedom and p -values are reported, if the sphericity assumption was violated (Mauchly test $p < .05$). Generalized eta-squared as provided by the R-package *ez* (Lawrence, 2016) is reported as an effect-size estimate. As an effect size estimate for the t -tests used in additional analyses we report Cohen's d (for independent samples) or d_z (for dependent samples) computed with the R-package *lsr* (Navarro, 2015). A

corresponding set of Bayes factor analyses computed with the R-package BayesFactor (Morey & Rouder, 2018) is presented in the electronic supplement (Tables B1 – B5). Here, we report results from these analyses when comparing context effects for picture and sound stimuli. Figure 1 displays mean picture and sound naming latencies per cycle and context condition (for more detailed information see Tables S1a and S1b).

Figure 1
Mean naming latencies for pictures and sounds (in ms) from Experiment 1 by context and cycle. Error bars represent the SEM.

Naming latencies were longer in the homogeneous context than in the heterogeneous context, $F_1(1, 62) = 133.14$, $p < .001$, $\eta_p^2 = .035$, $F_2(1, 15) = 47.86$, $p < .001$, $\eta_p^2 = .108$. There was also an effect of cycle, $F_1(4.64, 287.75) = 67.31$, $p < .001$, $\eta_p^2 = .047$, $F_2(2.14, 32.10) = 34.15$, $p < .001$, $\eta_p^2 = .147$, reflecting longest naming latencies in cycle 1 and some variation over the remaining cycles. Both variables interacted, $F_1(7, 434) = 18.77$, $p < .001$, $\eta_p^2 = .013$, $F_2(7, 105) = 23.57$, $p < .001$, $\eta_p^2 = .147$.

.001, $\eta_g^2 = .046$, reflecting a trend towards facilitation in cycle 1 and interference from cycle 2 onwards. Latencies were longer in sound naming than in picture naming, $F_1(1, 62) = 21.29$, $p < .001$, $\eta_g^2 = .235$, $F_2(1, 15) = 61.17$, $p < .001$, $\eta_g^2 = .513$. Critically, the effect of context was larger for sound naming than for picture naming, $F_1(1, 62) = 48.83$, $p < .001$, $\eta_g^2 = .013$, $F_2(1, 15) = 20.41$, $p < .001$, $\eta_g^2 = .043$, although it was significant both in sound naming, $F_1(1, 31) = 98.07$, $p < .001$, $\eta_g^2 = .054$, $F_2(1, 15) = 37.01$, $p < .001$, $\eta_g^2 = .145$, and in picture naming, $F_1(1, 31) = 41.38$, $p < .001$, $\eta_g^2 = .015$, $F_2(1, 15) = 18.85$, $p = .001$, $\eta_g^2 = .111$. Stimulus type also interacted with cycle, $F_1(4.64, 287.75) = 10.68$, $p < .001$, $\eta_g^2 = .008$, $F_2(2.54, 38.14) = 8.30$, $p < .001$, $\eta_g^2 = .028$, primarily reflecting a larger drop in naming latencies for sounds than for pictures from cycle 1 to cycle 2. There was an interaction of stimulus type, cycle, and context, $F_1(7, 434) = 7.33$, $p < .001$, $\eta_g^2 = .005$, $F_2(3.67, 54.98) = 10.89$, $p < .001$, $\eta_g^2 = .020$, reflecting the fact that there was interference from cycle 3 onwards in picture naming and interference from cycle 2 onwards in sound naming and that the size of interference varied more strongly for sounds than for pictures across cycles. In the analysis of error rates, there was a main effect of cycle in the participant analysis, $F_1(5.55, 344.14) = 2.81$, $p = .013$, $\eta_g^2 = .018$, $F_2(2.98, 44.67) = 2.26$, $p = .095$, $\eta_g^2 = .031$, reflecting more errors in cycle 1 than in all other cycles and some variation over cycles 2 – 8. There were no other significant main effects or interactions, all $ps > .051$.

Experiment 1 replicated semantic interference in blocked-cyclic picture naming as observed in earlier studies and established semantic interference in blocked-cyclic sound naming. In both task versions, we observed a trend towards facilitation in cycle 1 and interference from cycle 2 (sound naming) or cycle 3 onwards (picture naming).

The observation of semantic interference in blocked-cyclic sound naming is a novel finding and suggests that the effect is not confined to blocked-cyclic picture

naming but generalizes to other blocked-cyclic naming task versions involving conceptually driven word production. Despite similarities to the picture naming data (e.g., a trend towards facilitation in cycle 1, presence of interference from cycle 2 or at least from cycle 3 onwards), there is also one striking difference. Semantic interference was much larger in sound naming than in picture naming (79 ms vs. 19 ms). This finding is also supported by corresponding Bayes factor analyses (see Table B1) which revealed that the interaction of context and stimulus type is included in the preferred model and that the data are more likely under this model than under the best model without that interaction, for participants $BF > 1,000$, for items $BF > 1,000$. One should note, however, that at the same time sound naming was slower than picture naming (693 ms vs. 581 ms, heterogeneous condition only). Thus, it could be that what looks like differently sized context effects is in fact just a result of this difference in performance speed. To address this issue we conducted two more analyses which compensated for the difference in performance speed. Specifically, we based one set of analyses on $\log_e$ -transformed raw data and another one on relative effects (or percentage increase, respectively: $[RT_{\text{hom}} - RT_{\text{het}}] * 100 / RT_{\text{het}}$). Should the size of the interference effect in these analyses persist to be larger for sounds than for pictures, there would be evidence that this pattern is not caused by general slowing (Cerella, 1990; Kliegl et al., 1994; Oberauer et al., 2003). The analyses on $\log_e$ -transformed data revealed that interference in sound naming was still larger, $t_1(46.92) = 6.84$, $p < .001$, $d = 1.710$, $BF_{10} > 1,000$; $t_2(15) = 4.46$, $p < .001$, $d_z = 1.115$, $BF_{10} = 75$. This was also true for the analyses on relative effects, $t_1(44.51) = 6.80$, $p < .001$, $d = 1.700$, $BF_{10} > 1,000$; $t_2(15) = 4.61$, $p < .001$, $d_z = 1.152$, $BF_{10} = 97$. Thus, these additional analyses show that the differently sized interference effect cannot be attributed to a difference in performance speed in sound and picture naming. Rather, they indicate that a homogeneous context is more detrimental for

sound naming than for picture naming. Before putting too much weight on a single novel observation (interference in sound naming) and its property (larger than in picture naming), we wished to replicate this observation in a design in which the two stimulus types were presented intermixed.

Experiment 2

Experiment 2 was similar to Experiment 1 except that pictures and sounds were presented intermixed. The critical questions were (a) whether the interference effect in sound naming would be replicated, and (b) whether it would again be larger than the effect in picture naming.

Method

Participants. Thirty-two participants (22 females, mean age = 25.16 years, range = 19 – 32 years, $SD = 3.65$) were tested.

Materials, Apparatus, Design, and Procedure. Same as in Experiment 1, with the following differences. During familiarization, pictures and corresponding sounds were presented simultaneously (pictures for 3 secs) and their names appeared 1 sec later below the pictures; participants were again asked to read the names aloud³. During practice, each picture-sound pair was presented without name; participants were asked to name it again as quickly and as accurately as possible. In the experimental phase, each participant named pictures and sounds that were presented intermixed.

³ In contrast to Experiment 1, we decided to postpone the onset of the target names during familiarization to avoid that participants would focus primarily on the (instantly available) pictures at the expense of attending to the sounds (unfolding over time). This procedural change during familiarization was maintained in all subsequent experiments.

The number of responses per participant for any given item was identical to Experiment 1 (8 per context condition). However, because half of the items were presented as pictures and half of them as sounds, the number of cycles per stimulus type was reduced from eight to four. Within the first four trials and the last four trials of the new cycles, each item was presented once, in half of the cases as picture and in half of the cases as sound (this was counterbalanced by creating two versions of 16 pseudorandomized experimental lists, same randomization constraint as before). As a consequence, no more than four stimuli of the same stimulus type would occur in adjacent trials. Other than in Experiment 1, stimulus type was tested within-participants and within-items.

Results and Discussion

The raw data were treated as before. According to these criteria, 3.17% of all observations were excluded from the latency analysis and 2.65% entered the error analysis. Figure 2 displays picture and sound naming latencies per cycle and context condition (for more detailed information see Tables S2a and S2b).

Figure 2

Mean naming latencies for pictures and sounds (in ms) from Experiment 2 by context and cycle. Error bars represent the SEM.

Naming latencies were longer in the homogeneous context than in the heterogeneous context, $F_1(1, 31) = 185.50$, $p < .001$, $\eta_p^2 = .118$, $F_2(1, 15) = 66.32$, $p < .001$, $\eta_p^2 = .159$. There was also an effect of cycle, $F_1(1.66, 51.47) = 70.68$, $p < .001$, $\eta_p^2 = .131$, $F_2(3, 45) = 91.68$, $p < .001$, $\eta_p^2 = .172$, reflecting the fact that naming latencies became faster over cycles. Both variables interacted, $F_1(2.37, 73.45) = 12.93$, $p < .001$, $\eta_p^2 = .013$, $F_2(1.86, 27.86) = 7.35$, $p = .003$, $\eta_p^2 = .018$, reflecting smaller interference in cycle 1 than in cycles 2 – 4. Latencies were longer in sound naming than in picture naming, $F_1(1, 31) = 120.52$, $p < .001$, $\eta_p^2 = .378$, $F_2(1, 15) = 53.94$, $p < .001$, $\eta_p^2 = .459$. Critically, the effect of context was larger for sound naming than for picture naming, $F_1(1, 31) = 68.46$, $p < .001$, $\eta_p^2 = .034$, $F_2(1, 15) = 21.80$, $p < .001$, $\eta_p^2 = .047$, although it was significant both in sound naming, $F_1(1, 31) = 152.86$, $p < .001$, $\eta_p^2 = .158$, $F_2(1, 15) = 46.79$, $p < .001$, $\eta_p^2 = .191$; and in picture naming, $F_1(1, 31) = 66.68$, $p < .001$, $\eta_p^2 = .080$, $F_2(1, 15) = 45.29$, $p < .001$,

$\eta_g^2 = .212$. Stimulus type also interacted with cycle, $F_1(2.04, 63.24) = 26.02$, $p < .001$, $\eta_g^2 = .031$, $F_2(3, 45) = 37.03$, $p < .001$, $\eta_g^2 = .042$, reflecting a stronger decrease in naming latencies for sounds than for pictures across cycles. Finally, there was an interaction of stimulus type, cycle, and context, $F_1(3, 93) = 10.77$, $p < .001$, $\eta_g^2 = .008$, $F_2(3, 45) = 6.89$, $p < .001$, $\eta_g^2 = .011$, reflecting the fact that interference in sound naming varied more strongly across cycles than interference in picture naming. In the analysis of error rates, there was a main effect of context in the item analysis, $F_1(1, 31) = 3.72$, $p = .063$, $\eta_g^2 = .008$, $F_2(1, 15) = 5.41$, $p = .035$, $\eta_g^2 = .023$, reflecting a trend towards more errors in the homogeneous than in the heterogeneous context. There was also a main effect of cycle in the participant analysis, $F_1(2.02, 62.53) = 4.16$, $p = .020$, $\eta_g^2 = .014$, $F_2(3, 45) = 2.71$, $p = .056$, $\eta_g^2 = .040$, reflecting a trend towards more errors in cycle 1 than in all other cycles. There were no other significant main effects or interactions, all $ps > .112$.

As in Experiment 1, interference was larger in sound naming than in picture naming. This finding is also confirmed by corresponding Bayes factor analyses (see Table B2) which revealed that the interaction of context and stimulus type is included in the preferred model and that the data are more likely under this model than under the best model without that interaction, for participants $BF > 1,000$, for items $BF > 1,000$. As for Experiment 1, we again evaluated the size of the interference effect in sound and picture naming while compensating for differences in overall performance speed. When the analyses were performed on $\log_e$ -transformed raw latencies, interference in sound naming was still larger than interference in picture naming, $t_1(31) = 7.71$, $p < .001$, $d_z = 1.363$, $BF_{10} > 1,000$; $t_2(15) = 4.85$, $p < .001$, $d_z = 1.213$, $BF_{10} > 100$. The same was true when performing the analyses on relative effects, $t_1(31) = 7.57$, $p < .001$, $d_z = 1.339$, $BF_{10} > 1,000$; $t_2(15) = 4.46$, $p < .001$, $d_z = 1.114$, $BF_{10} = 75$. Thus, the differently sized interference effects cannot be attributed to a

difference in performance speed in sound and picture naming. Rather, the findings from Experiment 2 confirm that a semantic context is more detrimental for sound naming than for picture naming.

Experiment 1 had shown the typical finding from blocked-cyclic naming studies, namely no effect or (a trend towards) facilitation in cycle 1 and interference from cycle 2 (or at least from cycle 3) onwards. At first glance, this seems to be different for Experiment 2, in which interference was present already in cycle 1. Note, however, that cycles were differently defined in Experiment 1 than in Experiment 2. In the former, in line with other extant studies, a cycle was defined as one repetition of each of 4 items in one stimulus type (picture or sound). In the latter, however, a cycle was defined as one repetition of each of 4 items in each of two stimulus types (picture and sound, i.e., 2 repetitions per item). To evaluate whether also in a design with intermixed stimulus types the semantic context effect develops in the same way as with a fixed stimulus type, we performed an additional set of analyses in which we treated any presentation of four items (regardless of stimulus type) as a cycle (with the consequence that there were only 2 instead of 4 observations per stimulus type per cycle from each participant). For pictures, there was no effect of context at cycle 1 (4 ms slower responses in the homogeneous context, $SE = 10$ ms, 95% $CI = [-16; 24]$ for the participant analysis; 7 ms slower responses in the homogeneous context, $SE = 15$ ms, 95% $CI = [-23; 37]$ for the item analysis; $ps > .623$). The same was true for sounds (10 ms faster responses in the homogeneous context, $SE = 26$ ms, 95% $CI = [-62; 42]$ for the participant analysis; 18 ms faster responses in the homogeneous context, $SE = 30$ ms, 95% $CI = [-78; 42]$ for the item analysis, $ps > .562$). For all later cycles, there was significant interference with pictures and sounds (all $ps < .04$). In short, semantic interference in Experiment 2 with mixed stimulus types showed the same developmental pattern as semantic interference with fixed

stimulus types as observed in Experiment 1 and as reported in the literature (for picture stimuli).

Experiment 2 replicated the finding of semantic interference in sound naming from Experiment 1. This effect was again larger than the one in picture naming, even when the two types of stimuli are presented intermixed. The additional analyses on transformed latencies strongly suggest that the differently sized interference effects are no result of different base speeds in picture versus sound naming. But what else could be the reason for the differently sized effects then? Because in both task versions participants responded with the same words, all processes after the identification of a lexical target concept (or a set of semantic features defining that concept) are shared between task versions and thus cannot be responsible. Above, we have mentioned a few differences between picture naming and sound naming that might contribute to longer sound naming latencies than picture naming latencies. One difference is the time needed for perceptual analysis and identification, which takes longer for sounds than for pictures (see Murray & Spierer, 2009; Potter, 2014). Experiments 3 and 4 explored whether this initial processing phase (longer for sounds than for pictures) causes the difference in effect size. They did so by manipulating the ease of perceptual processing and identification of picture stimuli. If the prolongation of early processes is causing the disproportionate increase of semantic interference in sound naming, then the effect should similarly increase when perceptual processing and identification of picture stimuli is made more difficult.

Experiment 3

In Experiment 3, participants named intact and distorted pictures that were presented intermixed by producing the names of the objects (e.g., “dog”). The critical

question was whether semantic interference would be enhanced when perceptual processing (of the distorted pictures) takes more time.

Method

Participants. Thirty-two participants (25 females, mean age = 23.28 years, range = 18 – 36 years, $SD = 5.35$) were tested.

Materials, Apparatus, Design, and Procedure. Same as in Experiment 1, with the following differences. The (intact) color pictures were replaced by corresponding greyscale versions⁴. The sounds were replaced by distorted pictures that were created by applying a mesh-warp filter to the greyscale pictures (for details see <https://osf.io/73btq/>). During familiarization, an intact and the corresponding distorted picture were presented side by side (3 secs; position was counterbalanced for the types of pictures). Their names appeared 1 sec after the onsets of the two stimuli below the pictures. During practice, both pictures were presented side by side too, but without name. In the experimental phase, each participant named intact and distorted pictures that were presented intermixed.

Results and Discussion

The raw data were treated as before. According to these criteria, 2.95% of all observations were excluded from the latency analysis and 2.11% entered the error analysis. Figure 3 displays intact and distorted picture naming latencies per cycle and context condition (for more detailed information see Tables S3a and S3b).

⁴ We used greyscale versions of the pictures to rule out that color could be used as an effective cue for the quick identification of some of the distorted pictures.

Figure 3

Mean naming latencies for intact and distorted pictures (in ms) from Experiment 3 by context and cycle. Error bars represent the SEM.

Naming latencies were longer in the homogeneous context than in the heterogeneous context, $F_1(1, 31) = 49.41, p < .001, \eta_p^2 = .046, F_2(1, 15) = 17.49, p = .001, \eta_p^2 = .077$. There was also an effect of cycle, $F_1(3, 93) = 196.64, p < .001, \eta_p^2 = .166, F_2(1.20, 17.93) = 38.69, p < .001, \eta_p^2 = .263$, reflecting slower naming latencies in cycle 1 than in all other cycles. Both variables interacted, $F_1(3, 93) = 15.34, p < .001, \eta_p^2 = .017, F_2(1.77, 26.60) = 8.10, p = .002, \eta_p^2 = .030$, reflecting the fact that there was no effect in cycle 1, but interference from cycle 2 onwards. Latencies were longer in distorted picture naming than in intact picture naming, $F_1(1, 31) = 305.68, p < .001, \eta_p^2 = .092, F_2(1, 15) = 25.53, p < .001, \eta_p^2 = .153$. Critically, however, the effect of context did not differ between intact and distorted picture naming, $F_s < 1$. Stimulus type also interacted with cycle, $F_1(3, 93) = 48.15, p < .001, \eta_p^2 = .043, F_2(1.47, 21.98) = 14.57, p < .001, \eta_p^2 = .076$, reflecting a stronger decrease in

naming latencies for distorted than for intact pictures across cycles. There was no significant interaction of stimulus type, cycle, and context, $F_1(3, 93) = 1.04$, $p = .380$, $\eta_g^2 = .001$, $F_2 < 1$. In the analysis of error rates, there was a main effect of context in the item analysis, $F_1(1, 31) = 3.30$, $p = .080$, $\eta_g^2 = .005$, $F_2(1, 15) = 4.58$, $p = .049$, $\eta_g^2 = .013$, reflecting a trend towards more errors in the homogeneous than in the heterogeneous context. In addition, there was a main effect of cycle, $F_1(2.37, 73.58) = 3.94$, $p = .018$, $\eta_g^2 = .018$, $F_2(3, 45) = 3.17$, $p = .033$, $\eta_g^2 = .043$, reflecting more errors in cycle 1 than in all other cycles. There were no other significant main effects or interactions, all $ps > .084$.

As expected, distorted pictures were named more slowly than intact pictures, which can be attributed to slower perceptual processing of the distorted pictures. However, there was no difference in semantic interference between intact and distorted picture naming. This finding is also supported by corresponding Bayes factor analyses (see Table B3) which revealed that the interaction of context and stimulus type is not included in the preferred model and that the data are more likely under this model than under the best model including that interaction, for participants $BF = 6.52$, for items $BF = 4.87$. A likely reason is that the distortion manipulation applied to the pictures was not strong or persistent enough to sufficiently slow down perceptual processing of the (distorted) pictures to take effect. For example, in Experiment 2, sounds were named about 150 ms slower than intact pictures, whereas in Experiment 3, distorted pictures were named only about 40 ms slower than intact pictures.

Because a more pronounced distortion manipulation of the type applied in Experiment 3 would render most of the pictures non-recognizable, we opted for a different approach to slow down the perceptual processing of picture stimuli effectively in Experiment 4. Specifically, we blurred the pictures and stepwise brought

them into focus. This procedure might resemble initial stages in sound processing more closely than the one used in Experiment 3, because the full perceptual information would unfold over time, as is the case for sound stimuli.

Experiment 4

In Experiment 4, participants named intact pictures and blurred pictures that were stepwise brought into focus by producing the names of the objects (e.g., “dog”). Both types of pictures were presented intermixed. The critical question was whether the semantic interference effect would be enhanced when perceptual processing (of the initially blurred pictures) takes more time.

Method

Participants. Thirty-two participants (20 females, 1 diverse, mean age = 23.12 years, range = 18 – 34 years, $SD = 3.93$) were tested. One of them was replaced because of being unfocused and sleepy.

Materials, Apparatus, Design, and Procedure. Same as in Experiment 3, with the following differences. Distorted pictures were replaced by blurred pictures. The blurring effect was gradually removed (24 steps, each lasting 33 ms [i.e., 2 refresh cycles], for details see <https://osf.io/73btq/>). After 800 ms, the fully focused (i.e., intact) picture appeared and remained on the screen for another 700 ms. During familiarization and practice, only the blurred pictures were presented.

Results and Discussion

The raw data were treated as before. According to these criteria, 3.65% of all observations were excluded from the latency analysis and 3.27% entered the error

analysis. Figure 4 displays intact and blurred picture naming latencies per cycle and context condition (for more detailed information see Tables S4a and S4b).

Figure 4

Mean naming latencies for intact and blurred pictures (in ms) from Experiment 4 by context and cycle. Error bars represent the SEM.

In the participant analysis, naming latencies were longer in the homogeneous context than in the heterogeneous context, $F_1(1, 31) = 18.24$, $p < .001$, $\eta_p^2 = .009$, $F_2(1, 15) = 3.62$, $p = .076$, $\eta_p^2 = .013$. There was also an effect of cycle, $F_1(2.14, 66.38) = 146.80$, $p < .001$, $\eta_p^2 = .130$, $F_2(1.62, 24.23) = 102.59$, $p < .001$, $\eta_p^2 = .188$, reflecting the fact that naming latencies became faster over cycles. Both variables interacted, $F_1(3, 93) = 7.79$, $p < .001$, $\eta_p^2 = .006$, $F_2(3, 45) = 7.07$, $p = .001$, $\eta_p^2 = .008$, reflecting a trend towards facilitation in cycle 1 and significant interference from cycle 2 onwards. Latencies were longer in blurred picture naming than in intact picture naming, $F_1(1, 31) = 814.89$, $p < .001$, $\eta_p^2 = .766$, $F_2(1, 15) = 219.07$, $p < .001$, $\eta_p^2 = .832$. Critically, the effect of context did not differ between intact and blurred

picture naming, $F_1(1, 31) = 1.23$, $p = .275$, $\eta_g^2 = .000$, $F_2 < 1$. Stimulus type also interacted with cycle, $F_1(3, 93) = 117.64$, $p < .001$, $\eta_g^2 = .075$, $F_2(1.80, 26.94) = 101.20$, $p < .001$, $\eta_g^2 = .112$, reflecting a stronger decrease in naming latencies for blurred pictures than for intact pictures across cycles. There was no significant interaction of stimulus type, cycle, and context, $F_1(3, 93) = 1.38$, $p = .254$, $\eta_g^2 = .001$, $F_2(3, 45) = 1.05$, $p = .381$, $\eta_g^2 = .001$. In the analysis of error rates, there was a main effect of cycle in the item analysis, $F_1(3, 93) = 2.33$, $p = .079$, $\eta_g^2 = .014$, $F_2(3, 45) = 4.81$, $p = .005$, $\eta_g^2 = .032$, reflecting more errors in cycle 1 than in all other cycles. In addition, there was an interaction of context and cycle, $F_1(3, 93) = 3.02$, $p = .034$, $\eta_g^2 = .015$, $F_2(3, 45) = 2.99$, $p = .041$, $\eta_g^2 = .034$, reflecting some differential variation of errors across cycles in the homogeneous and heterogeneous context. There was a main effect of stimulus type, $F_1(1, 31) = 9.72$, $p = .004$, $\eta_g^2 = .018$, $F_2(1, 15) = 6.87$, $p = .019$, $\eta_g^2 = .039$, reflecting more errors in intact picture naming than in blurred picture naming. There were no other significant main effects or interactions, all $ps > .065$.

Blurred pictures were named substantially slower than intact pictures and this effect persisted over cycles. In fact, blurred pictures in Experiment 4 were named about 250 ms slower than sounds in Experiments 1 and 2. This slowing down was most likely due to extended perceptual processing needed for perceptual analysis and identification. Despite this fact, there was no difference in semantic interference for intact and blurred picture naming, unlike what was found for intact pictures and sounds in Experiments 1 and 2. This finding is also supported by corresponding Bayes factor analyses (see Table B4) which revealed that the interaction of context and stimulus type is not included in the preferred model and that the data are more likely under this model than under the best model including that interaction, for participants $BF = 5.60$, for items $BF = 4.78$. These results suggest that a mere

slowing down of perceptual processing and identification does not explain why sounds still yield larger interference effects than do pictures in naming.

In the introduction, we have mentioned the possibility that the connections between perceptual, semantic and lexical representations might differ for pictures and sounds. Specifically, sounds (e.g., *barking_{dog}*) might be associated more strongly with the corresponding action (e.g., barking) than with the object producing that sound (e.g., dog), whereas pictures are more strongly associated with the displayed object than with the action (see Mätzig et al., 2009, for a review). Because our participants were instructed to name the pictures and sounds with their corresponding object names, an additional transformation process might have been needed in sound naming (but not in picture naming) to generate the less preferred (but task relevant) response. Possibly, this could not only explain why sound naming took longer than picture naming but also why semantic interference was larger with sounds than with pictures.

Experiment 5 addressed this issue. Participants were asked to name pictures and sounds either with the corresponding object names or action names. If sounds are more strongly associated with actions than with objects and pictures more strongly associated with objects than with actions, and this differential strength is responsible for the longer latencies and larger semantic interference observed for sounds than for pictures in object naming in Experiments 1 and 2, the pattern observed in object naming should be reversed in action naming. That is, latencies in action naming should be longer and semantic interference should be larger for pictures than for sounds. For object naming, in contrast, the pattern from Experiments 1 and 2 should be replicated.

Experiment 5

In Experiment 5, participants named pictures and sounds that were presented intermixed by producing either the names of the objects (e.g., “dog”) or the action (e.g., “barking”). The critical question was whether the differences in latencies and semantic interference for pictures and sounds would reverse as a function of response format (object name vs. action name).

Method

Participants. Sixty-four participants (55 females, mean age = 23.59 years, range = 18 – 35 years, $SD = 4.63$) were tested. Half of them were assigned to the object naming task, and the other half to the action naming task. One participant was replaced because s/he had already participated in a previous experiment of this series.

Materials, Apparatus, Design, and Procedure. Same as in Experiment 2, with the following differences. Half of the items were replaced to allow for a manipulation of response format (object vs. action naming). There were again sixteen color photographs of common objects, four from each of four semantic categories (same as in the previous experiments), and corresponding sounds (mean duration = 1,092 ms, range = 764 – 1,480 ms, $SD = 244$ ms), see Appendix B. For half of the items, object and action names were morphologically related (e.g., “Hammer” [hammer] – “hämmern” [hammering]), and for the other half of the items they were not (e.g., “Hund” [dog] – “bellen” [barking]). The additional variable response format (object naming vs. action naming) was tested between participants but within items. During familiarization, pictures and sounds were presented simultaneously either with their corresponding object names or with the names of their associated actions (depending on the assigned response format).

Results and Discussion

The raw data were treated as before. According to these criteria, 3.86% of all observations were excluded from the latency analysis and 3.40% entered the error analysis. Figure 5 displays picture and sound naming latencies per cycle and context condition in object naming and action naming (for more detailed information, see Tables S5a – S5d).

Figure 5

Mean object naming and action naming latencies for pictures and sounds (in ms) from Experiment 5 by context and cycle. Error bars represent the SEM.

Naming latencies were longer in the homogeneous context than in the heterogeneous context, $F_1(1, 62) = 103.48$, $p < .001$, $\eta_p^2 = .020$, $F_2(1, 15) = 15.61$, $p = .001$, $\eta_p^2 = .075$. There was also an effect of cycle, $F_1(1.76, 108.92) = 240.98$, $p < .001$, $\eta_p^2 = .113$, $F_2(1.25, 18.74) = 110.10$, $p < .001$, $\eta_p^2 = .337$, reflecting the fact that naming latencies became faster over cycles. Both variables interacted, $F_1(2.66,$

165.05) = 7.15, $p < .001$, $\eta_g^2 = .001$, $F_2(1.78, 26.67) = 5.01$, $p = .017$, $\eta_g^2 = .006$, reflecting larger interference in cycles 2 – 4 than in cycle 1. Latencies were longer in sound naming than in picture naming, $F_1(1, 62) = 101.92$, $p < .001$, $\eta_g^2 = .233$, $F_2(1, 15) = 60.79$, $p < .001$, $\eta_g^2 = .545$. The effect of context was larger for sound naming than for picture naming but this interaction was not significant in the item analysis, $F_1(1, 62) = 44.11$, $p < .001$, $\eta_g^2 = .003$, $F_2(1, 15) = 4.52$, $p = .051$, $\eta_g^2 = .011$.

However, the effect of context was significant both in sound naming, $F_1(1, 62) = 94.04$, $p < .001$, $\eta_g^2 = .022$, $F_2(1, 15) = 11.18$, $p = .004$, $\eta_g^2 = .081$; and in picture naming, $F_1(1, 62) = 69.52$, $p < .001$, $\eta_g^2 = .026$, $F_2(1, 15) = 18.83$, $p = .001$, $\eta_g^2 = .106$. Stimulus type also interacted with cycle, $F_1(2.35, 145.82) = 93.44$, $p < .001$, $\eta_g^2 = .022$, $F_2(1.17, 17.50) = 22.19$, $p < .001$, $\eta_g^2 = .083$, reflecting a stronger decrease in naming latencies for sounds than for pictures across cycles. There was an interaction of stimulus type, cycle, and context, $F_1(2.65, 164.41) = 3.49$, $p = .021$, $\eta_g^2 = .001$, $F_2(3, 45) = 3.10$, $p = .036$, $\eta_g^2 = .002$, reflecting the fact that interference became larger for sounds than for pictures over cycles. The effect of response format was only significant in the item analysis, $F_1 < 1$, $F_2(1, 15) = 12.31$, $p = .003$, $\eta_g^2 = .018$, reflecting longer naming latencies in action naming than in object naming. In addition, there was an interaction of response format and cycle, $F_1(1.76, 108.92) = 3.97$, $p = .026$, $\eta_g^2 = .002$, $F_2(3, 45) = 8.31$, $p < .001$, $\eta_g^2 = .007$, reflecting a stronger decrease in action naming latencies than object naming latencies over cycles. There were no other significant interactions, all $ps > .058$. In the analysis of error rates, there was a main effect of context, $F_1(1, 62) = 6.13$, $p = .016$, $\eta_g^2 = .006$, $F_2(1, 15) = 8.38$, $p = .011$, $\eta_g^2 = .010$, reflecting more errors in the homogeneous than in the heterogeneous context. There was a main effect of cycle, $F_1(2.65, 164.55) = 15.47$, $p < .001$, $\eta_g^2 = .043$, $F_2(1.80, 27.06) = 9.19$, $p = .001$, $\eta_g^2 = .072$, reflecting more errors in cycle 1 than in all other cycles. In addition, there was an interaction of stimulus

type and cycle, $F_1(2.71, 167.96) = 7.13$, $p < .001$, $\eta_g^2 = .015$, $F_2(3, 45) = 3.51$, $p = .023$, $\eta_g^2 = .026$, reflecting the fact that error rates varied more strongly for sounds than for pictures over cycles. In the item analysis, there was an interaction of stimulus type and response format, $F_1(1, 62) = 3.95$, $p = .051$, $\eta_g^2 = .003$, $F_2(1, 15) = 4.58$, $p = .049$, $\eta_g^2 = .006$, reflecting more errors for sounds than for pictures in object naming but not in action naming. There were no other significant main effects or interactions, all $ps > .062$.

As in Experiments 1 and 2, interference was larger in sound naming than in picture naming, which, however, was confined to the participant analysis in the frequentist analyses. This finding is also supported by corresponding Bayes factor analyses (see Table B5) which revealed that the interaction of context and stimulus type is included in the preferred model and that the data are more likely under this model than under the best model without that interaction, for participants $BF = 11.23$, for items $BF = 4.79$. As in the comparison of the data from Experiments 1 and 2, we also evaluated the size of the interference effect in sound and picture naming (collapsed over response format) while compensating for differences in overall performance speed. When the analyses were performed on $\log_e$ -transformed raw latencies, interference in sound naming was still larger than interference in picture naming in the participant analysis, $t_1(63) = 5.94$, $p < .001$, $d_z = 0.742$, $BF_{10} > 1,000$; $t_2(15) = 1.82$, $p = .089$, $d_z = 0.454$, $BF_{10} = 0.97$. The same was true when performing the analyses on relative effects, $t_1(63) = 5.81$, $p < .001$, $d_z = 0.726$, $BF_{10} > 1,000$; $t_2(15) = 1.67$, $p = .117$, $d_z = 0.416$, $BF_{10} = 0.80$. However, this pattern was not substantiated in the item analyses, which is in contrast to Experiments 1 and 2. We assume that this shortcoming in Experiment 5 is due to a high variability among the (new) items whose selection was severely limited due to the additional constraint imposed by this experiment (manipulation of response format).

With some qualification regarding the item analysis (see above), Experiment 5 replicated the core finding from Experiments 1 and 2, namely larger semantic interference in sound naming than in picture naming. The novel finding from Experiment 5 is that the relative size of the interference effect for sounds and pictures is not modulated by the response format (object naming vs. action naming). This is also supported by corresponding Bayes factor analyses (see Table B5) which revealed that the interaction of context, stimulus type, and response format is not included in the preferred model and that the data are more likely under this model than under the best model including that interaction, for participants $BF = 64.74$, for items $BF = 31.07$. Would the looser link between perceptual, semantic, and lexical representations in object naming with sounds as opposed to pictures be the source of the larger interference effect with sounds in Experiments 1 and 2, the relative size of the interference effect should have reversed in action naming. Clearly, it did not; the two response formats yielded identical data patterns.

General Discussion

In a series of blocked-cyclic picture and sound naming experiments we observed that semantic interference in homogeneous contexts as compared to heterogeneous contexts is not only obtained with target pictures but also with target sounds and that the effects show a similar development (Experiments 1 and 2). These observations testify to the generality of the effect. Moreover, and most interestingly, the effect was differently sized for the two types of stimuli. Interference in picture naming (on average about 27 ms) was similar sized as what is typically reported in the literature (e.g., Abdel Rahman & Melinger, 2007; Damian & Als, 2005; Damian et al., 2001). Interference in sound naming (on average about 94 ms),

however, was much larger. This held true when stimulus types were tested separately (Experiment 1) and when stimulus types were tested intermixed (Experiment 2). Although performance speed was much slower in sound naming than in picture naming, the differently sized interference effects cannot be explained in terms of proportional slowing (i.e., linear scaling of effects). The pattern also persisted when analyses were based on $\log_e$ -transformed latencies or on the relative size of the effect, compensating for differences in performance speed. Experiment 3 and 4 asked whether the larger interference effect with sounds could be a result of prolonged perceptual analysis and identification. We tested this possibility by manipulating the ease of perceptual picture identification. The manipulations led to longer naming latencies but had no impact on the size of the interference effect. Experiment 5 explored the possibility that differences in the strength of the connections between perceptual, semantic and lexical representations for pictures and sounds might be responsible for the differently sized interference effects. Sounds might be associated more strongly with the corresponding action than with the object producing that sound, whereas pictures are more strongly associated with the displayed object than with the action (see Mätzig et al., 2009, for a review). We did not find any support to the notion that such differences between stimulus types and conceptual or lexical representations (of objects and actions) might have been the driving force behind our main finding, because Experiment 5 revealed that the effect of semantic context was more detrimental for sound naming than for picture naming in both object and action naming.

Another possible source of the differentially sized interference effect in picture and sound naming could be differences in the perceptual similarity of pictures versus sounds across contexts. Exemplars from a semantic category tend to share perceptual features, thus the perceptual similarity of stimuli in homogeneous contexts

could be larger than the perceptual similarity of stimuli in heterogeneous contexts. In fact, de Zubizaray et al. (2018) have recently demonstrated a detrimental effect of perceptual similarity in the absence of semantic similarity in blocked-cyclic picture naming⁵. One could further speculate that such a possible difference in perceptual similarity between homogeneous and heterogeneous contexts might be differently sized for sounds and pictures. Specifically, if sound identification would be more strongly hampered in homogeneous contexts than picture identification due to stronger perceptual similarity among semantically related sounds, a stronger context effect for sound naming than for picture naming would result as a natural consequence. Results from a norming study are instructive here. Prior to the experiments, we had evaluated possible differences in perceptual similarity across semantic contexts for picture and sound stimuli used in Experiments 1 and 2. An independent group of 12 participants (10 females, mean age = 27.17 years, range = 20 – 43 years, $SD = 6.39$) rated all possible combinations of two picture or two sound stimuli in homogeneous and heterogeneous contexts on a 5-point Likert scale (1 – little perceptual similarity, 5 – strong perceptual similarity). Stimulus type was blocked and counterbalanced across participants. The two stimuli to be compared were presented sequentially with a 300 ms pause in between; the sequence of stimulus type was also counterbalanced between participants. Picture duration was set to 800 ms, sound duration depended on the respective audio recording. Participants were instructed to evaluate the perceptual similarity of the two stimuli only, independent of semantics and other factors. For pictures, we obtained mean ratings of 2.50 (range:

⁵ In this study, the difference in perceptual similarity between homogeneous and heterogeneous contexts was, by design, amplified to test whether this factor by itself can, in principle, become effective. On a 7-point Likert scale (1 – they do not look similar at all; 7 – they look very similar), the mean rating was 5.54 for the homogeneous condition and 1.31 for the heterogeneous condition. This difference is a multiple of that in any other blocked-cyclic naming study for which ratings are available, including the present one.

1.33 – 4.58, $SD = 0.84$, $SE = 0.24$) for the homogeneous context and 2.00 (range: 1.33 – 2.63, $SD = 0.41$, $SE = 0.12$) for the heterogeneous context; this difference was significant, $t_1(11) = 2.90$, $p = .014$, $d_z = 0.838$, $BF_{10} = 4.42$; $t_2(15) = 5.13$, $p < .001$, $d_z = 1.283$, $BF_{10} > 200$. For sounds, we obtained mean ratings of 2.36 (range: 1.50 – 2.92, $SD = 0.46$, $SE = 0.13$) for the homogeneous context and 2.03 (range: 1.29 – 3.08, $SD = 0.54$, $SE = 0.16$) for the heterogeneous context; this difference was also significant, $t_1(11) = 2.38$, $p = .036$, $d_z = 0.688$, $BF_{10} = 2.13$; $t_2(15) = 2.44$, $p = .027$, $d_z = 0.611$, $BF_{10} = 2.42$. Although we had tried to minimize possible differences across context conditions (e.g., by using pictures showing some of the objects from a non-canonical perspective), it was evidently not possible to completely rule them out. Note, however, that the same was true for previous studies. For example, Damian et al. (2001) reported a difference of 0.48 between homogeneous and heterogeneous contexts with picture stimuli (also measured with a 5-point Likert scale). The authors considered the value for the homogenous context as “only slightly higher” than the value for the heterogeneous context (p. B79). A subset of these materials was also used in Damian and Als (2005). Belke et al. (2005) also took most experimental pictures from that study and considered them to be “tightly controlled for visual similarity” (p. 674). Thus, it seems that a complete elimination of perceptual differences between homogeneous and heterogeneous contexts is very difficult, if possible at all, so that this variable might indeed have contributed to the semantic interference effect from various blocked-cyclic naming studies, including the present one. Critically, however, for the materials we used in the present study the difference in perceptual similarity ratings across contexts was not larger for sounds than for pictures, $t_1(11) = 0.71$, $p = .492$, $d_z = 0.205$, $BF_{10} = 0.36$; $t_2(15) = 0.88$, $p = .392$, $d_z = 0.221$, $BF_{10} = 0.36$. Thus, whatever the precise role of a difference in perceptual similarity of stimuli between contexts in blocked-cyclic naming might be, this variable

cannot explain our key finding that semantic interference was substantially larger with sounds than with pictures.

There are some other data that also speak against perceptual similarity as the driving force behind the differently sized interference effect in sound and picture naming. In a recent study, we investigated semantic context effects from distractor pictures in sound naming (Wöhner et al., 2020). We observed semantic context effects (i.e., congruency facilitation with congruent distractor pictures and semantic interference with semantically related distractor pictures compared to unrelated distractor pictures) that were much larger than what is typically found in picture naming with distractor words (e.g., Damian & Martin, 1999) or distractor sounds (e.g., Mädebach et al., 2017). Importantly, perceptual similarity does not play a role in these studies as target and distractor stimuli were of different types, or presented in different sensory modalities, or both. These findings are in line with the notion that perceptual similarity unlikely accounts for differently sized semantic context effects in picture and sound naming as reported here.

Another issue to consider is the existence of alternative onomatopoeic verbal labels for some of the sounds (e.g., “bowwow”, “moo”), frequently used in child-directed speech and thus acquired early in life. Given that age of acquisition is a powerful variable affecting lexical processing (see Laing, 2019, for a review), it could be that these alternative verbal labels, even though not used frequently in adult language, were strongly activated by sounds specifically and then acted as powerful competitors, causing the boost in interference. According to our intuition, there are 4 items (out of the 16 used in Experiments 1 and 2) for which such onomatopoeic verbal labels are often used in child language (dog: “bowwow”; cow: “moo”; pig: “oink”, motorcycle: “vroom”). For these items, the context effect in sound naming amounted to 93 ms ($SD = 90$ ms, $SE = 16$ ms; Experiment 2), which is similar to the

113 ms ($SD = 55$ ms, $SE = 10$ ms) context effect in sound naming for the other items (including e.g., organ, bagpipe, drum, and saw). This pattern renders it rather unlikely that the activation of alternative onomatopoeic verbal labels by sound stimuli caused the boost in interference.

There are presently two main accounts for semantic interference in blocked-cyclic naming. The first assumes that the effect reflects lexical competition, that is, accumulating competitor activation in homogeneous blocks (e.g., Belke, 2013; Roelofs, 2018). The second assumes that the effect reflects incremental learning at the interface of semantic and lexical representations (Oppenheim et al., 2010). These accounts (and different versions of them) differ in many important aspects, including, for instance, the proposed structure of the conceptual representations (holistic vs. distributed) providing input into the lexical network. However, common to both accounts is that neither incorporates explicit assumptions about modality specific lead-in processes. For instance, the starting point of the competitive model by Roelofs (2018) is the selection of the lexical concept of the target (termed flagging of the goal concept). Similarly, the learning model by Oppenheim et al. (2010) assumes that pictures activate semantic features of the target in an all-or-none manner. Possible differences between sound and picture processing, for instance with regard to how fast or how strong the target concept is activated are beyond the scope of either model. Both models can readily explain why semantic interference is found in both sound and picture naming because the critical mechanism (competitive selection vs. incremental learning) concerns processes and representations, which should be the same in picture and sound naming. However, neither model – given its current scope – can readily explain why semantic interference is substantially larger in sound naming.

In the introduction, we have mentioned that the mapping of a stimulus onto a single conceptual (or lexical) representation might be less straightforward for sounds than for pictures. Specifically, some authors have argued in favor of coarse-to-fine semantic processing of naturalistic sounds (Murray et al., 2006; 2008; see Murray & Spierer, 2009, for a review). That is, upon initial processing the sound stimulus might reveal that it comes from an animal or musical instrument, but the more specific source is identified only later on. Although a similar point has been made for pictures (e.g., Mack & Palmeri, 2015; see Clarke, 2015; Fabre-Thorpe, 2011; for reviews), the temporal progression from coarse-to-fine semantic activation may differ between sounds and pictures. If so, sounds could lead to more diffuse initial activation in the conceptual-lexical system than pictures. This, in turn, could boost the competition when the target word is to be selected among a set of strongly co-activated competitors. Note that this idea does not conflict with our finding that semantic interference was not increased when perceptual picture processing was slowed down (Experiments 3 and 4), because it was not necessarily the case that our manipulations (distortion, blurring) led to a similar shift in the progression of coarse-to-fine processing of the picture stimuli.

Whatever the precise source of the differently sized interference in blocked-cyclic sound and picture naming might be, this finding per se is theoretically important as it provides strong evidence that semantic interference in blocked-cyclic naming tasks cannot be attributed to lexical processes exclusively (see also Belke, 2013). If it was, one would not expect any difference in semantic interference between task versions using different stimulus types triggering the same naming responses. This is for the simple reason that the task versions share all core processes of lexical retrieval. Thus, our finding indicates that there are important differences in the way sounds and pictures make contact with and are processed in the semantic-

conceptual system interfacing between the perceptual and the lexical system and that these differences affect word production subsequently in an important way.

Conclusion

Our experiments consistently showed that a semantic context hampered sound naming more strongly than picture naming in the blocked-cyclic naming task, even though lexical retrieval processes were identical. This finding suggests that semantic context effects obtained in that task are no pure reflection of core processes of word production but also contain contributions from lead-in processes (e.g., perceptual processing and conceptual identification) depending on the nature of the input stimulus. This is important to consider when using data obtained with the blocked-cyclic naming task in the evaluation of models of word production or models of semantic processing.

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Appendix

Appendix A

List of the target names used in Experiments 1 – 4. English translations are given in brackets.

	Heterogeneous 1 (mixed)	Heterogeneous 2 (mixed)	Heterogeneous 3 (mixed)	Heterogeneous 4 (mixed)
Homogeneous 1 (vehicles)	Auto [car]	Zug [train]	Schiff [ship]	Motorrad [motorcycle]
Homogeneous 2 (musical instruments)	Orgel [organ]	Dudelsack [bagpipe]	Gitarre [guitar]	Trommel [drum]
Homogeneous 3 (animals)	Schwein [pig]	Kuh [cow]	Pferd [horse]	Hund [dog]
Homogeneous 4 (tools)	Hammer [hammer]	Bohrer [drill]	Säge [saw]	Schere [scissors]

Appendix B

List of the object (top) and action (bottom) names used in Experiment 5. Approximate English translations are given in brackets.

	Heterogeneous 1 (mixed)	Heterogeneous 2 (mixed)	Heterogeneous 3 (mixed)	Heterogeneous 4 (mixed)
Homogeneous 1 (vehicles)	Rakete [rocket]	Fahrrad [bicycle]	Kanu [canoe]	Auto [car]
	zischen [hissing]	klingeln [ringing]	paddeln [canoeing]	hupen [honking]
Homogeneous 2 (musical instruments)	Flöte [flute]	Geige [violin]	Trompete [trumpet]	Rassel [rattle]
	flöten [playing the flute]	geigen [playing the violin]	trompeten [trumpeting]	rasseln [rattling]
Homogeneous 3 (animals)	Kuh [cow]	Hund [dog]	Schwein [pig]	Pferd [horse]
	muhen [mooing]	bellen [barking]	grunzen [grunting]	wiehern [neighing]
Homogeneous 4 (tools)	Hammer [hammer]	Schaufel [shovel]	Säge [saw]	Bohrer [drill]
	hämmern [hammering]	schaufeln [shoveling]	sägen [sawing]	bohren [drilling]