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ORIGINAL ARTICLE

Concurrent semantic priming and lexical interference for close semantic relations in blocked-cyclic picture naming: Electrophysiological signatures

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Abstract

In the present study, we employed event-related brain potentials to investigate the effects of semantic similarity on different planning stages during language production. We manipulated semantic similarity by controlling feature overlap within taxonomical hierarchies. In a blocked-cyclic naming task, participants named pictures in repeated cycles, blocked in semantically close, distant, or unrelated conditions. Only closely related items, but not distantly related items, induced semantic blocking effects. In the first presentation cycle, naming was facilitated, and amplitude modulations in the N1 component around 140–180 ms post-stimulus onset predicted this behavioral facilitation. In contrast, in later cycles, naming was delayed, and a negative-going posterior amplitude modulation around 250–350 ms post-stimulus onset predicted this interference. These findings indicate easier object recognition or identification underlying initial facilitation and increased difficulties during lexical selection. The N1 modulation was reduced but persisted in later cycles in which interference dominated, and the posterior negativity was also present in cycle 1 in which facilitation dominated, demonstrating concurrent effects of conceptual priming and lexical interference in all naming cycles. Our assumptions about the functional role these two opposing forces play in producing semantic context effects are further supported by the finding that the joint modulation of these two ERPs on naming latency exclusively emerged when naming closely related, but not unrelated items. The current findings demonstrate that close relations, but not distant taxonomic relations, induce stronger semantic blocking effects, and that temporally overlapping electrophysiological signatures reflect a trade-off between facilitatory priming and interfering lexical competition.

KEYWORDS

blocked-cyclic picture naming, EEG, lexical selection, semantic facilitation/interference, semantic similarity

1 | INTRODUCTION

Categorization is one of the first things we learn when navigating the environment, constructing knowledge of the world. By categorizing objects and beings according to how similar they are, we form semantic representations and assign them names. Thus, when we speak, we constantly refer to things with different levels of semantic similarity. Semantic similarity denotes the degree of relatedness between two words, for instance, words that share more semantic features under the same taxonomy, such as *horse* (has legs; is an animal) and *sheep* (has legs; is an animal), are more semantically similar than words that share fewer features, for example, *horse* and *shark* (does not have legs; is an animal). Manipulating semantic similarity offers insights into conceptual preparation and lexical selection during speech production and can reveal the micro-structure of our semantic system.

The present study investigated effects of semantic similarity on different planning stages during language production and aimed to provide a fine-grained time frame of the effects. Until now, to our knowledge, there is no electrophysiological evidence directly associated with semantic similarity effects in the blocked-cyclic naming paradigm. To pursue high temporal resolution information, we employed event-related potentials (ERPs) in a blocked-cyclic naming paradigm. To foreshadow the results, we find evidence for semantic facilitation for the first naming cycle that was predicted by an amplitude modulation of the N1 component, followed by semantic interference for later cycles that was predicted by a posterior negativity in the time range of the P2/N2 component. These effects were present only for close, but not for distant, semantic relations, indicating that only semantically close objects induce observable semantic context effects. Furthermore, the N1 modulation was reduced but persisted in later cycles in which interference dominated, and the posterior negativity was also present in the first cycle in which facilitation dominated, providing first evidence for temporally overlapping conceptual and lexical processing in the blocked-cyclic naming paradigm.

1.1 | Investigating semantic similarity in speech production paradigms

Semantic context effects serve as an index of lexical-semantic processing, which has been evidenced to take place around 200 ms after stimulus onset (e.g., Costa et al., 2009; Levelt, 1992; Levelt et al., 1999; Piai et al., 2014; Strijkers et al., 2010). Such effects emerge as facilitation or interference in different language production paradigms. To produce a word (e.g., *horse*), a speaker activates conceptual representations related to that word (e.g., mammal, fur, hooves), and the related concepts further activate one another's corresponding lexical representations. The most strongly activated target lexical representation (*horse*) is then selected from all the co-activated lexical candidates (e.g., *sheep*, *camel*) for articulation (Howard et al., 2006; Levelt et al., 1999; Roelofs, 1992, 2018). Based on models that assume lexical competition, the general mechanisms behind semantic context effects consist of two parts: conceptual priming and lexical competition. While related concepts facilitate the selection of a target lexical representation, co-activated lexical candidates compete with the target and thus disrupt selection (Abdel Rahman & Melinger, 2009, 2019; Belke et al., 2005; Roelofs, 2018). Since semantic context effects are assumed to require sufficient overlapping semantic features to emerge, enhancing semantic similarity should theoretically amplify the context effects. This hypothesis has been tested by studies applying different naming paradigms.

In the picture-word interference (PWI) paradigm (e.g., Damian & Bowers, 2003; Glaser & Düngelhoff, 1984; Glaser & Glaser, 1989; Hantsch et al., 2005; Hutson & Damian, 2014; Mahon et al., 2007; Piai et al., 2014; Rose et al., 2019; Schriefers et al., 1990; Vigliocco et al., 2004), participants are instructed to name a picture presented together with a superimposed distractor word which they should ignore. When a distractor word is categorically related to the picture, participants typically take more time to respond compared to pictures superimposed with an unrelated distractor word. The role of semantic similarity in lexical-semantic processing has been investigated with the PWI paradigm, but findings are inconsistent. While some studies found stronger interference for semantically close versus distant distractor words (e.g., Aristei & Abdel Rahman, 2013; Rose et al., 2019; Vigliocco et al., 2004), others found the opposite pattern (e.g., Mahon et al., 2007), and yet others found an overall effect of semantic relatedness, but no effect of semantic similarity (Hutson & Damian, 2014). Even when graded effects were observed behaviorally, electrophysiological evidence was only present for the semantically close condition (Rose et al., 2019), revealed as a posterior positivity around 200 ms poststimulus; no electrophysiological evidence of semantic interference was found for distant distractor words despite the behavioral effects.

In the continuous naming paradigm (e.g., Belke, 2013; Belke & Stielow, 2013; Costa et al., 2009; Howard et al., 2006; Navarrete et al., 2010), participants name pictures in succession. Semantically related picture sets are interleaved with unrelated filler items. A robust effect of ordinal position, that is, a linear increase in naming latency as the number of named exemplars of a given semantic category increases, has been reported for semantically related items, implying increasing difficulty of lexical selection. With regard to the effect of semantic similarity, in the continuous naming paradigm, cumulative interference has been reported for semantically close, but not for semantically distant, items (Rose & Abdel Rahman, 2017). In the same study, the cumulative interference was positively associated with a posterior positivity around 250 ms post-stimulus in the participants' electroencephalogram (EEG) *only* in the semantically close condition—an electrophysiological signature whose time course and scalp distribution agree with previously reported ERPs for lexical selection (Costa et al., 2009).

In order to make results across paradigms more comparable, our study focuses on another commonly used paradigm, the blocked-cyclic naming task (also referred to as the blocking paradigm; e.g., Belke, 2008; Belke et al., 2005; Damian & Als, 2005; Damian et al., 2001; Kroll & Stewart, 1994; Navarrete et al., 2012, 2014; Schnur et al., 2006; Vigliocco et al., 2002) while using the same set of materials as the two studies mentioned above that investigated the semantic similarity effects (Rose & Abdel Rahman, 2017; Rose et al., 2019). In the blocking paradigm, participants name exemplars from a given stimulus set in small repeated cycles; in homogeneous blocks, exemplars are semantically related, whereas in heterogeneous blocks, exemplars are semantically unrelated. From the second cycle onward, longer naming latencies in the homogeneous compared to the heterogeneous condition have been reliably reported, while either no effect or facilitation has been found in the first cycle (e.g., Abdel Rahman & Melinger, 2011; Crowther & Martin, 2014; Janssen et al., 2015; Navarrete et al., 2012). While findings in the first cycle have been less consistent, a review of studies using the blocked-cyclic paradigm found that facilitation is likely to be observed in the first cycle if the semantic conditions are presented in large blocks instead of in alternating order (Belke, 2017). How semantic similarity influences the process of lexical retrieval has also been investigated using the blocked-cyclic naming paradigm (e.g., Navarrete et al., 2012; Vigliocco et al., 2002). Behavioral studies have reported graded effects, with stronger facilitation in the semantically close versus distant condition in the first cycle (e.g., Navarrete et al., 2012, Experiment 1 & 2), and stronger interference in the semantically close versus distant condition (e.g., Vigliocco et al., 2002, collapsing all repetition cycles). However, there is no electrophysiological evidence directly associated with semantic similarity effects in the blocked-cyclic naming paradigm.

In sum, three different naming paradigms have been applied to test the effect of semantic similarity on lexical retrieval. While close relations usually produce context effects, such effects induced by distant relations are often absent or significantly weaker. One of our goals is thus to provide more evidence with regard to the extent to which semantic similarity modulates context effects. Moreover, even though EEG has been recorded in the PWI and continuous naming paradigms to examine the modulation of semantic similarity, the electrophysiological evidence for such modulation is absent in the blocked-cyclic paradigm.

1.2 | Theoretical explanations for semantic blocking effects

The semantic context effects in the blocked-cyclic paradigm, specifically referred to as *semantic blocking effects*, have been alternatively related to perceptual, conceptual, lexical, or post-lexical planning stages. The view that underpins the current investigation holds that semantic blocking effects, and indeed all semantic context effects, reveal a trade-off between conceptual and lexical processes, which temporally overlap. Specifically, the slower naming times observed in later homogeneous naming cycles result from the competitive nature of the lexical selection process[1] (cf. Levelt et al., 1999; Roelofs, 1992, 2018). A Swinging Lexical Network account argues that, in contrast to a heterogeneous blocking context, the repeated naming of a set of semantically related items in the homogeneous blocking condition results in a cohort of strongly co-activated candidates striving to be selected (Abdel Rahman & Melinger, 2009, 2019). The presence of this active cohort slows down lexical selection because all active candidates enter into a competition for selection, much like a tug of war.

Within the Swinging Lexical Network model, the facilitation observed in the first cycle arises due to easier object recognition: Object recognition is most difficult in the first cycle, and participants may profit from the semantic contexts (Abdel Rahman & Melinger, 2007). This gives conceptual priming an upper hand over lexical competition, following the aforementioned assumption that blocking effects reflect a trade-off between conceptual facilitation and lexical competition, two processes that temporally overlap and unfold in parallel (Abdel Rahman & Melinger, 2009, 2019; Rabovsky et al., 2021). Supporting this explanation, a recent study manipulating visual and semantic similarity using a non-repeated semantic priming paradigm found evidence for a perceptually related top-down

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[1] There are other models that do not assume a competitive lexical selection process (e.g., Oppenheim et al., 2010), but we focus on competitive models in this study.

bias underlying initial facilitation (Scheibel & Indefrey, 2020). In this study, participants named pictures in three conditions: semantic/lexical knowledge (primed by a category word), perceptual/conceptual knowledge (primed by a picture of the category's mean shape, generated by overlaying all exemplars within the given category) and no a priori knowledge (no prime preceding the picture). Naming visually consistent categories (e.g., birds) benefitted from both types of a priori knowledge more than visually variable categories (e.g., buildings). Furthermore, the facilitation based on a priori perceptual/conceptual knowledge was consistently larger than that based on a priori semantic/lexical knowledge. The authors argue that a priori perceptual/conceptual knowledge presented a top-down mechanism that limited the number of target-shape candidates and accelerated the feature matching procedure, thus facilitating the naming response.

1.3 | Tracking the functional architecture and time course of lexical selection

The basic assumption about the functional architecture of the just described model is that conceptual processing (typically reflected in facilitatory effects) and lexical selection (typically reflected in effects of interference) proceed in parallel (concurrent activation; for similar arguments of parallel processing, see Abdel Rahman & Sommer, 2003; Abdel Rahman et al., 2003; Feng et al., 2021; Strijkers et al., 2017). Note, this does not necessarily mean that both processes begin and end at the same time. Specifically, we assume continuous spread of activation within and between conceptual and lexical processing levels (cf. Roelofs, 1992, 2018). As a result, conceptual activation is initiated in an initial sweep before lexical activation, but conceptual activation does not stop when lexical activation begins. Rather, there is a period of time when both levels of processing are active and can in fact interact with each other. The period of overlapping conceptual and lexical activation and interaction results in the trade-off between facilitation and interference. The outcome of the trade-off depends on the situation and context in which pictures are named. For instance, in the blocking paradigm, when the semantic context is most helpful in the first cycles, semantic priming (facilitatory effects) dominates, whereas lexical interference dominates if many competitors are fully active at the lexical level, and the influence of conceptual priming should be reduced.

These aspects of the functional architecture of the language production system and the time course of conceptual and lexical processing can be investigated by employing the temporal precision of the EEG, as we will describe below (for EEG evidence in the blocking paradigm, e.g., Aristei et al., 2011; Janssen et al., 2011, 2015; Llorens et al., 2014; Wang et al., 2018; see de Zubicaray & Piai, 2019 for a comprehensive review). Across studies, a common finding of a larger ERP at posterior sites for the related compared to unrelated condition has been associated with the semantic blocking effect, although the polarity of the amplitude seems to differ. Aristei and colleagues (2011) incorporated the PWI task into the blocked-cyclic paradigm and found a larger negativity for homogeneous blocks starting at around 200–250 ms post-stimulus. This ERP was associated with the blocking effect based on the significantly different amplitudes when contrasting homogenous and heterogeneous blocks (see also an MEG study from Maess et al., 2002, which reports similar results), suggesting that the posterior negativity reflects lexical selection. A more recent study by Wang and colleagues (2018) reported a relative positivity at posterior sites for homogeneous blocks from 200 ms after stimulus onset. In sum, the evidence for the polarity of the electrophysiological signature of lexical selection remains inconsistent for the blocking paradigm.

1.4 | The present study

The first goal of the present study is to examine whether enhanced semantic similarity leads to stronger blocking effects. We frame our study within the context of competitive models of lexical selection because they provide clear and tractable predictions. Specifically, enhancing semantic similarity should theoretically lead to (a) stronger conceptual priming, thus stronger semantic facilitation in the first cycle, and (b) more intense lexical competition, thus increased semantic interference in later cycles.

In the first presentation cycle, we expect semantic facilitation to emerge. Furthermore, the strength of this effect should be influenced by semantic similarity, that is, stronger blocking effects in the semantically close condition than in the semantically distant condition. The expectation is based on the current large-block design, where initial facilitation has been reliably reported (Belke, 2017). To trace the electrophysiological signature of such facilitation induced by higher semantic similarity, we focused on relatively early ERP modulations within a latency range below 200 ms at posterior sites that should reflect object recognition, including perceptual and conceptual aspects (e.g., Itier & Taylor, 2004; Thorpe et al., 1996; Tokudome & Wang, 2012; Valente et al., 2014; Vogel & Luck, 2000).

For cycles 2–5, we predict that increasing semantic similarity results in stronger interference during lexical selection when naming semantically closely related pictures compared to naming distantly related ones. In addition, we expect a larger posterior negativity at temporal-parietal sites starting in the time range of the P2/N2 component at around 250 ms post-stimulus (cf. Aristei et al., 2011), which has been linked to the process of lexical selection, in the semantically close condition compared to the distant condition. While prior investigations using other naming paradigms reported converging evidence of a positive-going ERP for the semantic context effects (as reviewed in Section 1.1), in the blocked-cyclic naming paradigm, negative-going ERPs have also been reported (e.g., Aristei et al., 2011; Maess et al., 2002). Except for the polarity, both ERP look temporally and topographically similar.

The second goal of this study is to relate behavioral facilitation and interference in the first and later cycles to different planning stages and their relative time courses reflected by ERPs. We assume that conceptual priming and lexical interference start at different points in time relative to picture onset. As proposed above, we expected conceptual facilitation to start first, and be indexed by an earlier ERP modulation. While this process is still ongoing, lexical selection starts and will be indexed by a later ERP modulation (parallel/concurrent activation). Assuming that conceptual and lexical processing occur concurrently with opposite forces, regardless of the behavioral blocking effects, their respective ERP modulations should be present both in the first and in later cycles, modulating naming latency in opposite directions. The two ERPs should interactively be related to naming latency such that an enhanced N1 (related to facilitated object identification) would induce facilitation, while an enhanced P2/N2 (related to concomitant lexical competition) would induce interfering effects. Naming latencies are a result of the relative contributions of both effects. Crucially, these two ERP modulations should interactively influence naming behavior, indicating a joint modulation by both cognitive processes on naming latency across all cycles - in support of the trade-off assumption between conceptual facilitation and lexical competition.

In sum, our basic expectations were graded blocking effects depending on semantic similarity on both naming latencies and ERP amplitudes: Behaviorally, semantic blocking effects emerge as facilitation in the first cycle but turn into interference in later cycles, whereas cycle 1 facilitation should be accompanied by a relatively early ERP modulation and cycles 2–5 interference should be accompanied by a relatively late ERP modulation. In addition, based on the theoretical trade-off assumption, these two ERPs should modulate naming latencies in opposite directions and interact with each other, indicating a joint modulation on naming latencies, but only when semantic similarity is high.

2 | METHOD

The experiment was approved by the local ethics committee and was based on ethical principles put forward by the Declaration of Helsinki for research involving human subjects (Version 2013). The data that support the findings of this study are available in OSF at https://osf.io/jkzn9/?view_only=fcd144715c854731904736288dbd48ba.

2.1 | Participants

We collected data from 25 healthy, right-handed, native German speakers with normal or corrected-to-normal visual acuity and normal color vision. Participants were compensated with expense allowance or received credit towards their curriculum requirements. All participants gave informed consent prior to participation. The data from one participant had to be excluded due to excessive EEG artifacts, resulting in a total number of 24 participants (18 females, mean age 23.8) for data analyses. The sample size was determined based on previous work investigating semantic interference effects in different naming paradigms (e.g., Rose & Abdel Rahman, 2017; Rose et al., 2019), which are comparable to the blocking effects starting from the second presentation cycle.

2.2 | Materials

A total number of 125 colored photographs of objects were selected as picture stimuli. Stimuli and semantic relations were identical to Rose and Abdel Rahman (2017) and Rose and colleagues (2019), which manipulated the degree of semantic similarity in a systematic way. We manipulated semantic similarity by the semantic features that items share with closely related members in a sub-category, or with more distantly related members in an overarching category. For instance, an eagle shares more features with an owl and a parrot, but less with other animals such as a shark or a camel. In short, we varied the semantic feature overlap while keeping the overarching taxonomic category membership constant. Manual classification resulted in five broad categories (animals, clothes, tools, groceries, and furniture), each of which contained five sub-categories (e.g., animals: birds, fish, insects, ungulates, and monkeys; see Appendix A for the full stimulus list). Each sub-category consisted of five exemplars (e.g., birds: eagle, hummingbird, parrot, vulture, and owl). Each item was represented by a unique exemplar (i.e., we only included one image for "eagle"), and the same exemplar (image) was repeatedly named in a block.

The stimulus sets within each sub-category represented the *semantically close* blocking condition (hereafter the close condition). For the *semantically distant* blocking condition (hereafter the distant condition), we assigned one exemplar from each sub-category of a given broad category to form the stimulus sets (cf. Rose & Abdel Rahman, 2017; Rose et al., 2019). Finally, for the *semantically unrelated* blocking condition (hereafter the unrelated condition) we took one exemplar from each broad category. With this, all stimuli appeared in the close, distant, and unrelated stimulus sets. Visually, the selected pictures were typically not confused with other category members and were easy to identify. To avoid higher visual similarities between members in closely related sets influencing the expected effects, we selected our materials following two criteria: (1) pictures of objects are taken from different perspectives, without unnecessary similarities; (2) members in the closely related sets look visually different (e.g., eagle vs. owl). Using a computational similarity measure for images, the Haar wavelet-based perceptual similarity index (HaarPSI; Reisenhofer et al., 2018), we generated perceptual similarity indexes for all possible combinations between stimulus pictures. With the coefficients obtained from a Haar wavelet decomposition, local similarities between two images were assessed, including the relative importance of image areas. The average visual similarity is numerically relatively balanced across conditions (group means for close = .193; distant = .187; unrelated = .180), while an ANOVA test showed a significant difference between condition means, $F_{(2,678)} = 6.59$, $p = .001$. However, since the HaarPSI ranges from 0 to 1, differences less than 0.7% have little practical significance on visual similarity. All photographs were edited for a homogenous background color and scaled to the size of 3.5 cm × 3.5 cm. Stimuli were presented on a 4/3 17″ BenQ monitor with a resolution of 1,280 × 1,024 using Presentation® software (Version 18.0, Neurobehavioral Systems, Inc., Berkeley, CA) at a viewing distance of 60 cm, producing an equal stimulus size of 2.7° visual angle for each object stimulus.

2.3 | Procedure

Participants were familiarized with the stimuli prior to the main experiment as follows: Color print photographs were presented together with their names in random order on sheets of paper. Participants were asked to study the pictures and the corresponding names carefully. For the main experiment, participants were instructed to name pictures as fast and accurately as possible. On a screen with a light grey background, a fixation cross in the center indicated the start of a trial. After 0.5 s, a picture was presented for maximally 2 s, or disappeared as soon as the voice key was triggered. A blank screen followed and lasted for 1 s until the next trial started.

The experimental session consisted of three sections that corresponded to the three semantic blocking condition (close, distant, and unrelated). The ordering of conditions was counterbalanced across participants. The order of the stimulus sets within each condition was randomized. Each stimulus set was presented five times (five presentation cycles), and an online randomization was performed for each cycle separately. This resulted in 625 trials per semantic blocking condition (125 per presentation cycle) and a total trial number of 1,875.

2.4 | Acquisition and analyses

2.4.1 | Accuracy

In general, participants showed very high accuracy in naming pictures, and deviations were fairly low ($M = 99.88\%$, $SD = 0.12\%$). We ran a generalized linear mixed-effects model (GLMM) using the function *glmer* in the *lme4* package (Bates, Maechler, et al., 2015, version 1.1-21) in R (R Core Team, 2018) to test the accuracy as a function of block order to control for possible covariate. The random structure consisted of random intercepts of subject and item, and a random slope of block order for subject.

2.4.2 | Naming latencies

Naming latencies were measured with a voice key starting from stimulus onset to participants' response. Only those trials were analyzed in which participants named the picture correctly and without speech disfluency. According to these criteria, around 3.8% of the data had to be excluded. Naming latencies shorter than 200 ms (0.87%) were removed. We log-transformed the naming latencies based on the outcome of a Box-Cox Test in order to meet the normality assumption of linear mixed-effect models.

Of all trials, 91.76% entered data analyses. Aside from the pre-defined exclusion criteria, further trials were excluded due to EEG data loss. Since we aimed to predict naming latencies by ERP modulations on a trial-by-trial basis, we analyzed only those trials in which both behavioral and EEG data points survived the exclusion criteria, that is, correct naming within 200 ms and clean EEG signal. This resulted in a total of 8.11% of trials being excluded. While the sum of trials per participant was 1875, the number of trials removed was on average 152 (*SD* = 132) per participant. One participant's data in a whole condition block (one-third of all trials) was removed due to EEG recording issues.

Linear mixed-effects models (LMMs; Baayen et al., 2008) tested the relationship between log-transformed naming latencies and the predictors using R (R Core Team, 2018) and the *lme4* package (Bates, Maechler, et al., 2015, version 1.1-21). Separate analyses were conducted for cycle 1 and cycles 2–5. We entered into the model as fixed effects the critical factor Semantic Blocking, and, for the analyses of presentation cycles 2–5, the control factor Presentation Cycle, and their interaction terms. The predictor Semantic Blocking was contrast coded to compare the semantically close to the unrelated condition (*close* vs. *unrelated*) and the semantically distant to the unrelated condition (*distant* vs. *unrelated*)[2]. The predictor Presentation Cycle was centered and entered as a continuous variable.

To account for random effects, our model included intercepts for participants and items and random slopes for the fixed effect terms. Models were initially run with a maximum random effects structure. Since the maximal model failed to converge, we set all correlation parameters to zero by using the double-bar syntax (cf. Kliegl, 2014). Applying singular value decomposition, this initial random effect structure was simplified by successively removing those random effects whose estimated variance was zero until the maximal informative model was identified (cf. Bates, Kliegl, et al., 2015).

For fixed effects, we report fixed effect estimates, 95% confidence intervals, and *t* values. Fixed effects are considered significant if $|t| \geq 1.96$ (cf. Baayen et al., 2008), but we also computed *p*-values by Satterthwaite approximation (using the *summary* function in the *lmerTest* package, version 3.1-1; Kuznetsova et al., 2017). For random effects, we report estimates of variance as well as the standard deviations. Goodness-of-fit statistics are also reported.

2.4.3 | Event-related potentials

The continuous EEG was recorded with 62 Ag/AgCl electrodes, arranged according to the extended 10/20 system, online referenced to an electrode at the left mastoid. The sampling rate was 500 Hz. To register eye movements and blinks, electrodes were placed near the left and right corner of both eyes and above and beneath the left eye. Electrode impedance was kept below 5 kOhm.

Eye movements and blink artifacts in the EEG signals were identified by employing the Multiple Source Eye Correction (MSEC) method implemented in the BESA Research software (Version 6.0, BESA GmbH, Gräfelfing, Germany; Berg & Scherg, 1994). After identifying eye-movements artifacts, the raw EEG data were submitted to BrainVision Analyzer (Version 2.1.2, Brain Products GmbH, Gilching, Germany) for preprocessing. Offline EEG was re-referenced using the common average reference. The identified spatiotemporal patterns reflecting eye-movements artifacts were corrected by a linear derivative. To reduce noise, a low-pass filter was applied (high cutoff = 30 Hz, 24 dB/oct). The data was then segmented based on the reference marker, including all necessary markers. An interval starting from 100 ms before the stimulus onset was used for baseline correction to exclude stimulus-independent activity at the beginning of the segment. Remaining artifacts were eliminated with an automatic artifact rejection procedure, which excluded segments with potentials exceeding 50 μV voltage steps per sampling point and a threshold of 200 μV. The EEG data were then segmented again in epochs of 1,300 ms, starting 100 ms before the onset of the stimulus, to specify conditions for single-trial analysis. The resulting segments arranged according to experimental conditions were exported to MATLAB (Version 2019b, The MathWorks Inc., Natick, Massachusetts) for speech artifact correction.

Speech artifact correction

To tackle the severe artifacts induced by speaking in the EEG signals (e.g., Brooker & Donald, 1980; Grözinger et al., 1975; Wohlert, 1993), we implemented a MATLAB toolbox capable of correcting articulation-related artifacts: residue iteration decomposition (RIDE; Ouyang et al., 2016). This toolbox decomposes ERPs into separate component clusters with different trial-to-trial variabilities (e.g., stimulus-locked, response-locked, and latency-variable component clusters). Articulation artifacts can be identified from the EEG signal based on their large amplitudes and highly variable trial-to-trial latencies. By implementing RIDE, we decomposed the ERPs into the stimulus-locked S-component (search time window 0 to 600 ms after stimulus onset) and the response-locked R-component (i.e., articulation-related artifacts; search time window ±300 ms from response time, see Figure 1). The R-component (per participant and per condition) was then subtracted from the original ERPs for every single trial. The resulting cleaned ERPs were then matched to

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[2] We chose to set the unrelated condition to the baseline to keep our results comparable to other studies in the field. Yet where appropriate we also ran analyses with the distant condition as baseline. This did not change the general pattern of our findings. We report the central outcome of these analyses alongside our main results and give the full model outputs in the Supporting Information.

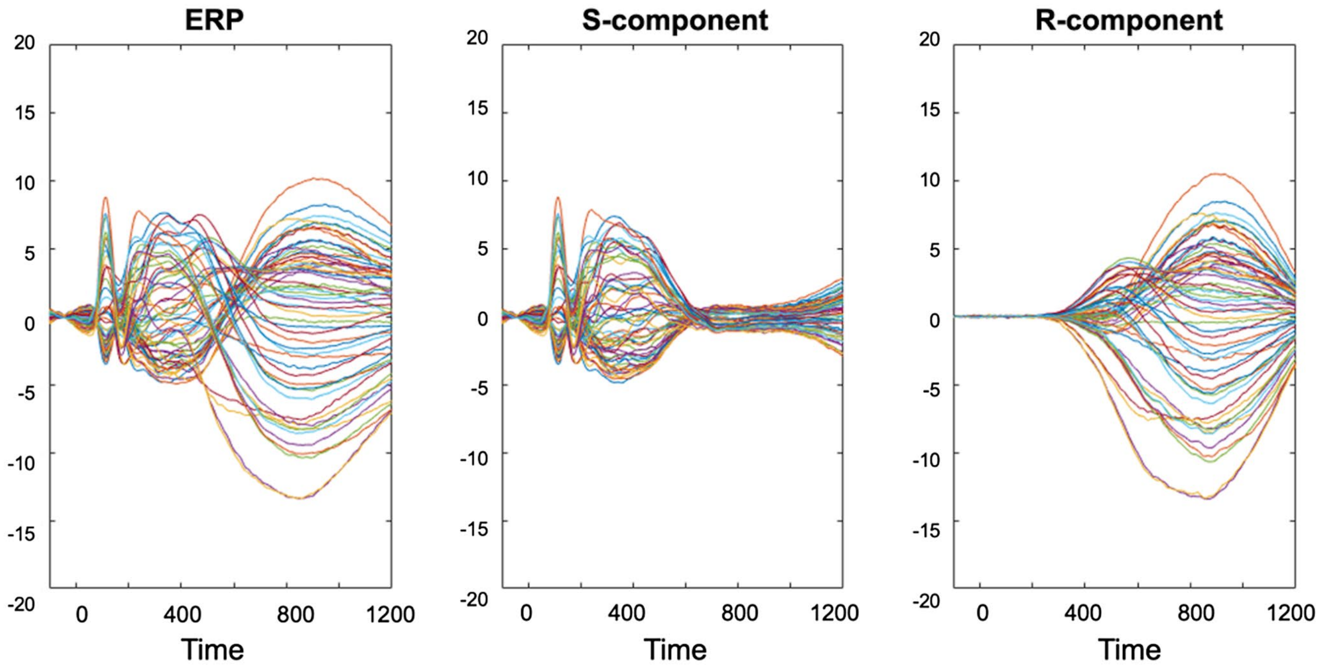

FIGURE 1 Component separation for artifact corrections with RIDE. The left plot shows the original ERPs prior to speech artifacts correction. The middle plot shows the S-component free of articulation-related noise, which was submitted to data analyses. The right plot shows the R-component, which was removed from the original ERPs

naming latencies on a trial-by-trial basis and exported to R for statistical analysis.

Analysis procedure

The general parameters and analysis procedure for models predicting ERP amplitudes were the same as the LMMs testing naming latencies, except that the predicted variable was replaced with the averaged EEG activities at the pre-defined ROIs and time windows.

Based on the hypothesis that conceptual priming should be strongest when participants name pictures for the first time in the semantically related contexts, likely restricted to the close context (cf. Abdel Rahman & Melinger, 2007; Scheibel & Indefrey, 2020), for cycle 1, we examined an ERP component reflecting the mechanism of object recognition and identification. Therefore, we analyzed EEG signals from the posterior sites, including electrodes TP9/10, P7/8, PO9/10, O1/2 (ROI for object recognition; Itier & Taylor, 2004) ranging from 140 to 180 ms after stimulus onset (the stage of visual complexity during picture naming; cf. Valente et al., 2014; see also other object recognition studies, e.g., Thorpe et al., 1996; Vogel & Luck, 2000).

For cycles 2–5, we hypothesized that lexical competition should be strongest when participants name pictures in semantically related contexts, particularly pictures with close relations. Here we examined the ERP amplitudes at the ROI and during the time window found in Aristei and colleagues' study (2011), in which brain activities were proposed to reflect changes during lexical retrieval in the blocked-cyclic naming paradigm. We selected two electrodes at the temporal-parietal sites, TP9 and TP10, as the ROI, and analyzed the EEG activities from 250 to 350 ms after stimulus onset.

In addition to our basic hypotheses and predictions that semantic facilitation in cycle 1 should be accompanied by a relatively early ERP modulation, and that lexical interference in cycles 2–5 should be accompanied by a relatively late ERP modulation, we took a step further to examine whether these two ERP modulations are active in parallel. This was based on the theoretical assumption that the concurrent processing of conceptual priming and lexical competition together contribute to the behavioral facilitatory or interfering blocking effects (cf. Swinging Lexical Network, Abdel Rahman & Melinger, 2009, 2019). In support of the trade-off hypothesis proposed in this framework, we should find concurrent traces of the early and late modulation in the selected ROIs across all cycles, with relative strengths. For this purpose, we separately ran a model testing the early modulation in cycles 2–5, as well as a model testing the late modulation in cycle 1.

2.4.4 | Relating behavior to brain activities

Assuming that ERPs reflect the underlying cognitive sources, whose changes can be observed behaviorally, the amplitude of ERPs relevant to lexical-semantic processing should serve as a good predictor for naming latencies. Another reason for conducting this brain-behavior analysis was to examine whether participants' naming behavior was really modulated by concurrent processing of conceptual priming and lexical competition across all cycles, and whether their naming behavior was modulated *together* by these two cognitive processes at the same time. To examine the first question, we entered the mean ERP amplitudes occurring in both early and late time windows as two fixed effects into a single LMM to predict log-transformed naming latencies. To examine the second question, we entered the interaction term between these two ERPs as another fixed effect on the naming latencies. Moreover, we recoded the predictor presentation cycle as a two-level categorical variable (*first* vs. *later*) to more precisely capture our research interest, that is, conceptual facilitation in the first cycle versus lexical interference in later cycles.

The random structure was selected following the same procedure as the other models described above. In order to reduce the complexity of the model so that the results could be more interpretable, we split the dataset according to the blocking condition. Since the results of both the naming latency and ERP models indicated that naming latencies in the distant condition did not vary much from the unrelated condition, here we only analyzed data from the close and unrelated conditions.

3 | RESULTS

3.1 | Accuracy

The overall accuracy was 99.82% in the first block, 99.95% in the second block, and 99.89% in the third block. The GLMM showed a slight trend of significance of the contrast Order 2 versus Order 1 ($\beta = 2.83$, $SE = 1.68$, $z = 1.68$, $p = .09$), and a null result for the contrast Order 3 versus Order 2 ($\beta = -1.66$, $SE = 1.75$, $z = -0.94$, $p = .34$). The finding indicates that participants' naming accuracy was not influenced by the order in which items were named in the close, distant or unrelated blocks.

3.2 | Naming latencies

3.2.1 | Cycle 1

In cycle 1, the mean naming latency in the close condition was 39 ms shorter than in the unrelated condition (semantic facilitation), while the naming latency in the distant condition was only 5 ms longer than in the unrelated condition (close: $M = 732$, $SD = 189$; distant: $M = 777$, $SD = 179$; unrelated: $M = 771$, $SD = 175$; see Figure 2). The descriptive statistics were confirmed by the identified LMM testing the semantic blocking effects in cycle 1. The model showed that the hypothesis-based fixed effect contrast close versus unrelated was statistically significant, whereas the contrast distant versus unrelated did not reach significance (see Table 1). Thus, supporting our hypothesis, we found semantic facilitation for semantically close items in cycle 1. Although there was no semantic context effect for semantically distant items, the unexpected finding is still consistent with our hypothesis that semantically distant items induce weaker effects—in this case, too weak to be detected.

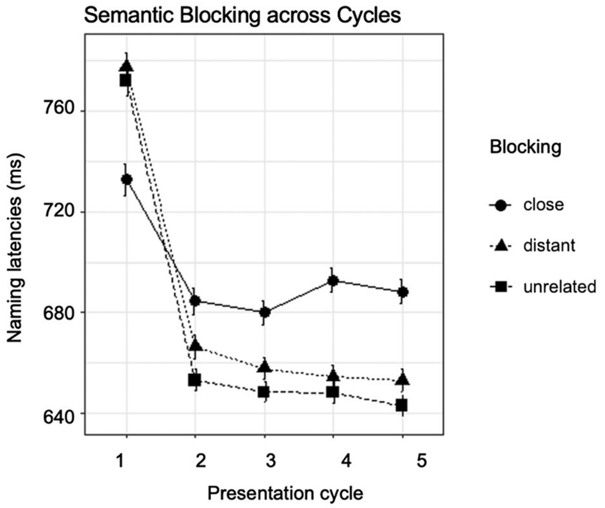

FIGURE 2 Naming latencies plotted against presentation cycles, grouped by semantic blocking condition. The figure shows that in the first cycle, participants named semantically closely related objects faster compared with naming distantly related or unrelated objects (semantic facilitation). From the second cycle onwards, the data pattern was reversed (semantic interference). The error bars refer to the 95% confidence intervals

3.2.2 | Cycles 2–5

From cycles 2 to 5, the mean naming latency in the close condition was 38 ms longer than in the unrelated condition, whereas in the distant condition, naming latency was only 9 ms longer than in the unrelated condition (semantic interference; close: $M = 686$, $SD = 156$; distant: $M = 658$, $SD = 140$; unrelated: $M = 648$, $SD = 135$; see Figure 2). The observed data patterns were confirmed by the identified LMM testing the semantic blocking effects in cycles 2–5. The model demonstrated that the fixed effect contrast close versus unrelated was statistically significant, whereas the contrast distant versus unrelated did not reach significance (see Table 2). This suggests that, as hypothesized, semantic interference arises in the semantically close condition; unexpectedly, no blocking effect was found in the semantically distant condition, possibly because the effect is too weak to be seen.

TABLE 1 Linear mixed-effects model of cycle 1 on log-transformed naming latencies, with the semantic blocking contrasts close versus unrelated and distant versus unrelated as predictors

Log-transformed naming latencies (cycle 1)					
Fixed effects					
Predictors		Estimates	95% *CI*	*t*	*p*
(Intercept)		0.014	−0.02 to 0.05	0.862	.393
Close versus unrelated		−0.064	−0.10 to −0.03	−3.376	.002**
Distant versus unrelated		0.006	−0.02 to 0.03	0.452	.655
Random effects					
Groups		Variance	*SD*		
Participant					
(Intercept)		0.005	0.070		
Close versus unrelated		0.007	0.085		
Distant versus unrelated		0.004	0.066		
Picture					
(Intercept)		0.008	0.094		
Close versus unrelated		0.005	0.076		
Residual		0.027	0.166		
Observations	7,536	$N_{\text{participant}}$	24	N_{picture}	125
Likelihood ratio test					
		X^2	*df*	*p*	
Close versus unrelated		9.643	1	.0019**	
Coding formula in R					

```
Log RT in cycle 1 ~ Semantic Blocking + (1 + Semantic Blocking ||participant) + (1 + close
   versus unrelated || picture)
```

Abbreviations: *CI*, confidence interval; *SD*, standard deviation.

** $p < .01$.

Interestingly, the above model also revealed a main effect of the presentation cycle, reflecting an incremental speed up of naming latencies across cycles (numerically, there was a total decrease of 6 ms from cycles 2 to 5). However, inspection of the naming latencies across presentation cycles distinguished by blocking condition reveals a more complex picture. Specifically, naming latencies increased from cycles 2 to 5 by 3 ms in the semantically close condition but decreased over cycles by 13 ms in the semantically distant condition, and by 9 ms in the unrelated condition.

3.3 | Event-related potentials

3.3.1 | Testing the basic hypotheses: Electrophysiological traces of facilitation and interference

Posterior N1 in cycle 1

The mean amplitude at posterior sites in the close condition was 0.85 μV more negative than in the unrelated condition, while the amplitude in the distant condition was only 0.03 μV more negative than in the unrelated condition (close: $M = -0.33$, $SD = 6.17$; distant: $M = 0.49$, $SD = 6.21$; unrelated: $M = 0.52$, $SD = 6.15$).

The LMM testing for traces of facilitation in cycle 1 demonstrated a statistically significant effect of the a priori contrast close versus unrelated (see Table 3, Figure 3a[upper],e). Similar to the behavioral LMM, the contrast distant versus unrelated did not reach significance (see Figure 3a[lower],e). The direction of the effect indicates a stronger negativity during the close condition compared to the unrelated condition. This posterior negativity during 140–180 ms is analogous to the typical visual N1 activities (e.g., Itier & Taylor, 2004; Thorpe et al., 1996; Tokudome & Wang, 2012; Vogel & Luck, 2000) and is in line with the visual complexity stage during picture naming (cf. Valente et al., 2014). These results supported our hypothesis that closely related pictures induced larger ERP modulations compared to unrelated pictures; there were no modulations of the ERPs in the distant condition. This finding is unexpected but consistent with our hypothesis that semantically distant items yield weaker effects; in this case too weak to be detected.

TABLE 2 Linear mixed-effects model of cycles 2–5 on log-transformed naming latencies, with the semantic blocking contrasts, presentation cycle, and their interaction as predictors

Log-transformed naming latencies (cycles 2–5)					
Fixed effects					
Predictors		Estimates	95% *CI*	*t*	*p*
(Intercept)		0.001	−0.03 to 0.03	0.073	.942
Close versus unrelated		0.056	0.04 to 0.08	5.476	<.001***
Distant versus unrelated		0.012	−0.00 to 0.03	1.407	.170
Presentation cycle		−0.002	−0.00 to −0.00	−2.719	.006**
Close versus unrelated: cycle		0.008	0.00 to 0.01	4.272	<.001***
Distant versus unrelated: cycle		−0.001	−0.01 to 0.00	−0.929	.352
Random effects					
Groups		Variance	*SD*		
Participant					
(Intercept)		0.006	0.079		
Close versus unrelated		0.001	0.043		
Distant versus unrelated		0.001	0.040		
Picture					
(Intercept)		0.002	0.050		
Close versus unrelated		0.002	0.052		
Distant versus unrelated		0.001	0.032		
Residual		0.025	0.160		
Observations	33,757	$N_{\text{participant}}$	24	N_{picture}	125
Likelihood ratio test					
		X^2		*df*	*p*
Close versus unrelated		21.23		1	<.001***
Presentation cycle		7.096		1	.007**
Close versus unrelated: cycle		18.241		1	<.001***
Coding formula in R					

```
Log RT in cycles 2–5 ~ Semantic Blocking * Presentation Cycle + (1 + Semantic Blocking ||
   participant) + (1 + Semantic Blocking || picture)
```

Abbreviations: *CI*, confidence intervals; *SD*, standard deviation.

** $p < .01$; *** $p < .001$.

Posterior negativity in the P2/N2 time range in cycles 2–5

The mean amplitude at temporal-parietal sites in the close condition was 0.6 μV more negative than in the unrelated condition, while the amplitude in the distant condition was only 0.34 μV more negative than in the unrelated condition (close: $M = -1.99$, $SD = 7.25$; distant: $M = -1.7$, $SD = 7.25$; unrelated: $M = -1.38$, $SD = 7.47$).

The LMM testing for electrophysiological signatures of semantic interference in cycles 2–5 demonstrated a statistically significant effect of the a priori contrast close versus unrelated (see Table 4). The effect direction indicates a larger negativity in the close versus unrelated condition from cycles 2 to 5 (see Figure 3d[upper],h). The contrast distant versus unrelated was marginally significant (see Figure 3d[lower],h). The posterior negativity in the semantically close condition replicates the finding in Aristei and colleagues' study (2011), in which the negative modulation reflects the semantic interference during lexical retrieval induced by the blocked-cyclic naming paradigm. Additionally, the LMM also showed a significant main effect of presentation cycle, indicating a positive-going activity over the course of the cycles. Finally, the interaction between the contrast close versus unrelated and presentation cycle was not significant. These results support our hypothesis that closely related pictures induced larger ERP modulations compared to unrelated pictures. Although distantly related pictures seem to yield little effects, this is still consistent with our hypothesis that

TABLE 3 Linear mixed-effects model of cycle 1 on the ERP component N1, with the semantic blocking contrasts close versus unrelated and distant versus unrelated as predictors

N1 (cycle 1)					
Fixed effects					
Predictors		Estimates	95% CI	*t*	*p*
(Intercept)		0.294	−0.88 to 1.47	0.493	.627
Close versus unrelated		−1.043	−1.48 to −0.61	−4.695	<.001***
Distant versus unrelated		−0.183	−0.52 to 0.16	−1.057	.300
Random effects					
Groups		Variance	*SD*		
Participant					
(Intercept)		8.313	2.883		
Close versus unrelated		0.672	0.820		
Distant versus unrelated		0.230	0.480		
Picture					
(Intercept)		0.930	0.964		
Close versus unrelated		0.245	0.495		
Residual		24.354	4.935		
Observations	7,536	$N_{\text{participant}}$	24	N_{picture}	125
Likelihood ratio test					
		X^2	*df*	*p*	
Close versus unrelated		16.322	1	<.001***	
Coding formula in R					

```
N1 in cycle 1 ~ Semantic Blocking + (1 + Semantic Blocking +Presentation Cycle || participant) +
   (1 + close versus unrelated || picture)
```

Abbreviations: *CI*, confidence intervals; *SD*, standard deviation.

***$p < .001$.

semantically distant pictures induce weaker effects than the close pictures.

3.3.2 | Testing the theoretical assumption: Concurrent processing of conceptual priming and lexical competition across all cycles

Posterior negativity in the P2/N2 time range in cycle 1

The mean amplitude at temporal-parietal sites in the close condition was 1.49 μV more negative than in the unrelated condition, while the amplitude in the distant condition was only 0.45 μV more negative than in the unrelated condition (close: *M* = −2.44, *SD* = 7.88; distant: *M* = −1.4, *SD* = 7.25; unrelated: *M* = −0.95, *SD* = 7.68).

To test for traces of semantic interference in cycle 1, we ran an LMM predicting the posterior negativity in the P2/N2 time range for cycle 1. This model demonstrated a statistically significant effect of the contrast close versus unrelated (see Table 5), indicating a larger negativity in the close versus unrelated condition in cycle 1 (see Figure 3b[upper],f). The contrast distant versus unrelated was not significant (see Figure 3b[lower],f). These results supported our hypothesis that even in the first presentation cycle, where participants showed facilitated naming behavior (associated with N1), traces of lexical competition can still be found, as indexed by the presence of the P2/N2 component.

Posterior N1 in cycles 2–5

The mean amplitude at posterior sites in the close condition was 0.47 μV more negative than in the unrelated condition, while the amplitude in the distant condition was 0.26 μV more negative than in the unrelated condition (close: *M* = −0.54, *SD* = 6.17; distant: *M* = −0.33, *SD* = 6.08; unrelated: *M* = −0.07, *SD* = 6.14).

To test for traces of facilitation in cycles 2–5, we report the LMM predicting the N1 component for cycles 2–5. The model demonstrated a statistically significant effect of the close versus unrelated contrast (see Table 6, Figure 3c[upper],g). In contrast to the behavioral LMM, the distant versus unrelated contrast was also significant (see Figure

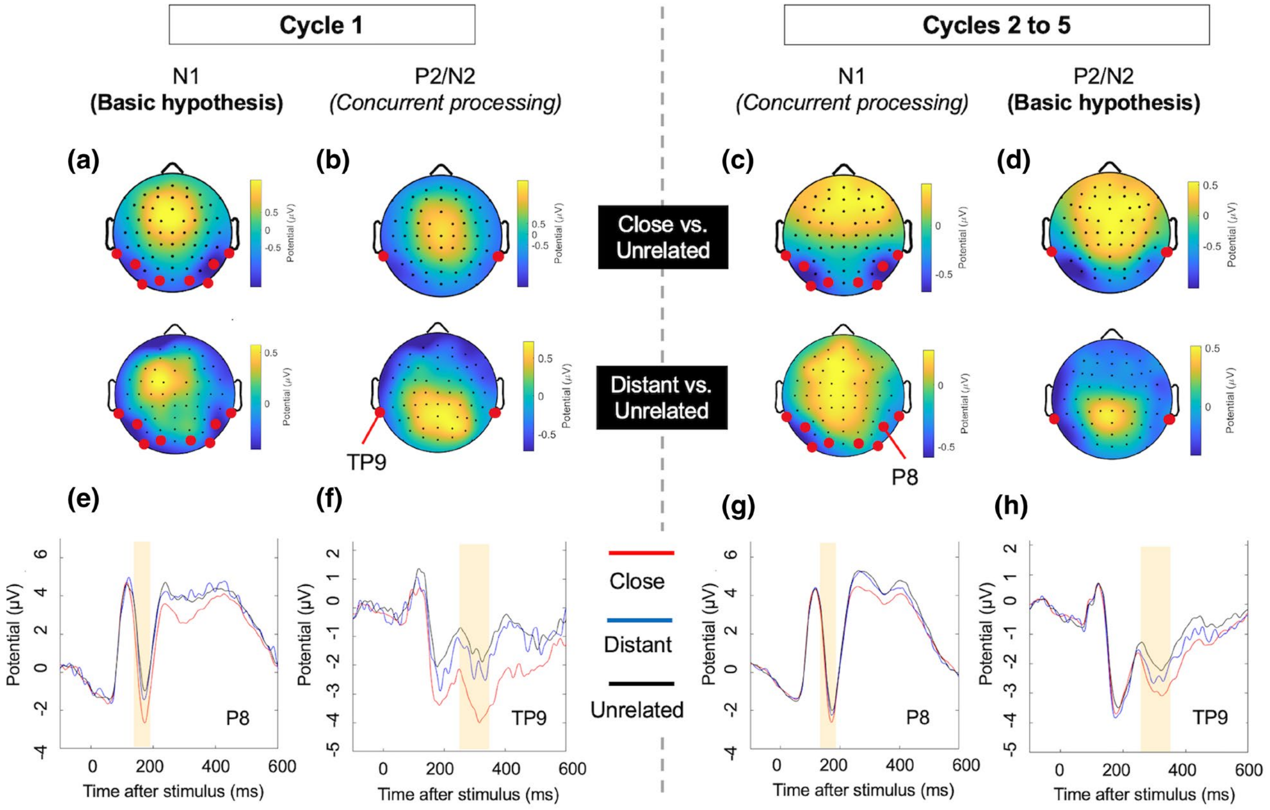

FIGURE 3 Electrophysiological results of cycle 1 and cycles 2–5. ROI for N1: TP9/10, P7/8, PO9/10, O1/2; ROI for the posterior negativity in the P2/N2 time range: TP9/10; both are highlighted with red dots in the topographies. (a) Posterior negativities from 140 to 180 ms in cycle 1; (b) temporal-parietal negativities from 250 to 350 ms in cycle 1; (c) posterior negativities from 140 to 180 ms in cycles 2–5; (d) temporal-parietal negativities from 250 to 350 ms in cycles 2–5; upper topographies illustrate the close versus unrelated contrast, and lower topographies illustrate the distant versus unrelated contrast. (e–h) illustrate the averaged brain activities in each semantic blocking condition at specific channels within the ROIs pre-defined for cycle 1 and cycles 2–5; the selected time windows of the ERP modulations are highlighted with yellow color

3c[lower],g), but the effect size was smaller than the close versus unrelated contrast. The direction of the effect indicates a stronger negativity during both the close and distant condition compared to the unrelated condition. Finding traces of N1 in later presentation cycles supports our hypothesis that even when participants show interference in their naming behavior, they experience easier object recognition in parallel.

3.3.3 | Predicting naming latencies by N1 and P2/N2

Until this step, the above LMMs testing the effect of semantic blocking condition on naming latencies and ERP amplitudes have demonstrated that both participants' behavioral and brain responses were indeed modulated by the semantic blocking condition, and to be more precise, by naming objects that are semantically close but not by semantically distant objects. Furthermore, we found indications that facilitatory processes, as indexed by N1, and interfering processes, as indexed by P2/N2 are concurrently active in both the first and later cycles. This provides first evidence for the trade-off between these processes as predicted by the Swinging Lexical Network model (cf. Abdel Rahman & Melinger, 2009, 2019).

To explore the predictive relationship between brain activities and naming responses across cycles, particularly when naming semantically closely related objects, we set up an LMM including presentation cycle, N1, P2/N2, as well as their interaction terms as fixed effects to predict log-transformed naming latencies in the close condition (see Table 7). This model showed significant effects of both N1 and P2/N2. The effect directions indicate that the stronger (more negative) the N1, the quicker the participants name the closely related pictures. In contrast, the stronger (more negative) the P2/N2, the slower the participants name the closely related pictures. The results support our hypotheses that N1 reflects the process of object recognition/identification, while P2/N2 reflects the process of lexical selection; furthermore, the two processes modulate naming latencies in parallel across all cycles.

TABLE 4 Linear mixed-effects model of cycles 2–5 on the posterior negativity in the P2/N2 time range, with the semantic blocking contrasts, presentation cycle, and their interaction as predictors

Posterior negativity in the P2/N2 time range (cycles 2–5)					
Fixed effects					
Predictors		Estimates	95% *CI*	*t*	*p*
(Intercept)		−1.708	−2.62 to −0.80	−3.678	.001**
Close versus unrelated		−0.601	−0.93 to −0.27	−3.591	.001**
Distant versus unrelated		−0.264	−0.54 to 0.01	−1.890	.070
Presentation cycle		0.182	0.08 to 0.29	3.457	.002**
Close versus unrelated: cycle		0.051	−0.09 to 0.19	0.730	.465
Distant versus unrelated: cycle		0.095	−0.04 to 0.23	1.355	.175
Random effects					
Groups		*Variance*	*SD*		
Participant					
(Intercept)		4.987	2.233		
Close versus unrelated		0.501	0.708		
Distant versus unrelated		0.308	0.555		
Presentation cycle		0.046	0.216		
Picture					
(Intercept)		0.825	0.908		
Close versus unrelated		0.126	0.355		
Residual		34.713	5.891		
Observations	33,757	$N_{\text{participant}}$	24	N_{picture}	125
Likelihood ratio test					
		X^2	*df*	*p*	
Close versus unrelated	10.397	1		.001**	
Presentation cycle	9.6422	1		.001**	
Close versus unrelated: cycle	0.533	1		.465	
Coding formula in R					
`P2/N2 in cycles 2-5 ~ Semantic Blocking * Presentation Cycle + (1 + Semantic Blocking + Presentation Cycle || participant) + (1 + close versus unrelated || picture)`					

Abbreviations: *CI*, confidence intervals; *SD*, standard deviation.

** $p < .01$.

In addition, there was a significant effect of presentation cycle, which indicates a general drop of naming latencies in later cycles compared to the first one, likely due to repetition priming.

Furthermore, we found a significant interaction between N1 and P2/N2. Judging from the effect pattern (see Figure 4), this result indicates that the N1 modulation on naming latencies is most salient when P2/N2 is weak, while the P2/N2 modulation on naming latencies is most salient when N1 is strong. This supports the theoretical hypothesis that there is a trade-off between concurrent processing of conceptual priming and lexical competition, respectively represented by N1 and P2/N2, affecting naming latencies with facilitatory and interfering modulations.

As a control analysis, we conducted a similar LMM for the unrelated condition including the same fixed effects to predict log-transformed naming latencies (see Table 8)[3]. Similar to the model testing data in the close condition,

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[3] Since we had unbalanced numbers of ROIs selected for the two ERPs (8 for N1 and 2 for P2/N2), we split the ROIs of N1 into all possible combinations of electrodes from each hemisphere, and iterated the analysis across all combinations such that we entered the same amount of data into the N1 and N2/P2 analyses. This resulted in a total of 16 sub-analyses. In the end, 15 out of all sub-analyses identified a significant interaction between N1 and P2/N2, similar to the effects reported in Tables 7 and 8, with the only exception being marginally significant (sub-ROI of N1: O1 and P8). We thus concluded that unbalanced numbers of ROIs did not affect our findings. We would like to thank an anonymous reviewer for recommending this analysis.

TABLE 5 Linear mixed-effects model of cycle 1 on the posterior negativity in the P2/N2 time range, with the semantic blocking contrasts, presentation cycle, and their interaction as predictors

Posterior negativity in the P2/N2 time range (cycle 1)					
Fixed effects					
Predictors		Estimates	95% *CI*	*t*	*p*
(Intercept)		−1.656	−2.80 to −0.51	−2.829	$<.001^{***}$
Close versus unrelated		−1.505	−1.94 to −1.07	−6.755	$<.001^{***}$
Distant versus unrelated		−0.342	−0.74 to 0.05	−1.708	.097
Random effects					
Groups		Variance	*SD*		
Participant					
(Intercept)		7.856	2.804		
Close versus unrelated		0.328	0.573		
Distant versus unrelated		0.221	0.471		
Picture					
(Intercept)		1.235	1.111		
Close versus unrelated		0.796	0.892		
Residual		37.245	6.102		
Observations	7,536	$N_{\text{participant}}$	24	N_{picture}	125
Likelihood ratio test					
		X^2	*df*	*p*	
Close versus unrelated	27.892	1		$<.001^{***}$	
Coding formula in R					

```
P2/N2 in cycle 1 ~ Semantic Blocking + (1 + Semantic Blocking ||
   participant) + (1 + close versus unrelated || picture)
```

Abbreviations: *CI*, confidence intervals; *SD*, standard deviation.

$^{***}p < .001$.

this model also showed significant effects of both N1 and P2/N2. The effect directions again demonstrated that the stronger the N1, the shorter the naming latencies; the stronger the P2/N2, the longer the naming latencies. The results here indicate that N1 is associated with a general recognition/identification process of objects, and that P2/N2 is associated with a general lexical selection process - both processing stages modulate naming behavior regardless of semantic blocking condition. Crucially, the model did not show a significant interaction between N1 and P2/N2.

To directly compare the effect sizes of this interaction term across two LMMs, we refit both models with a standardized version of the data (using the *standardized_parameters* function in the R-package *effectsize*, Version 0.4.4, Ben-Shachar et al., 2020). The standardized coefficient of the interaction between two ERPs was .02 in the close model, while the coefficient of the interaction was only .006 in the unrelated model. The absence of the interactive modulation of the two ERP components together on naming latencies is the only difference from the close model: It indicates that in the unrelated condition, naming behavior is not affected by a trade-off between conceptual priming and lexical competition, which occurs exclusively in the close condition.

Considering that close and distantly related items may share associative relations (co-existing in the same space, e.g., live in the forest) while unrelated items do not, we also ran an LMM predicting naming latency by N1 and P2/N2 amplitudes for the distant condition. The aim of this analysis was for direct comparison between close and distant relations. Critically, we found no interaction between both ERPs, as in the model for the unrelated condition reported above. The absence of any influence of the joint modulation of the two ERPs on naming latencies, which was exclusively observed in the close condition, supports our hypothesis that the behavioral semantic blocking effect was determined by a trade-off between priming and lexical competition. The supplemental analyses and results can be found in OSF via the link provided in the Method section.

4 | DISCUSSION

The present study tested the impact of semantic similarity on different planning stages during overt picture naming

TABLE 6 Linear mixed-effects model of cycles 2–5 on the ERP component N1, with the semantic blocking contrasts close versus unrelated and distant versus unrelated as predictors

N1 (cycles 2–5)					
Fixed effects					
Predictors		Estimates	95% *CI*	*t*	*p*
(Intercept)		−0.313	−1.41 to 0.79	−0.557	.582
Close versus unrelated		−0.471	−0.68 to −0.27	−4.482	<.001***
Distant versus unrelated		−0.337	−0.59 to −0.08	−2.611	.015*
Presentation cycle		−0.010	−0.10 to 0.08	−0.227	.822
Close versus unrelated: cycle		0.073	−0.04 to 0.19	1.272	.203
Distant versus unrelated: cycle		0.053	−0.06 to 0.17	0.905	.365
Random effects					
Groups		Variance	*SD*		
Participant					
(Intercept)		7.362	2.713		
Close versus unrelated		0.164	0.405		
Distant versus unrelated		0.287	0.536		
Presentation cycle		0.034	0.185		
Picture					
(Intercept)		1.028	1.014		
Residual		23.946	4.893		
Observations	33,757	$N_{\text{participant}}$	24	N_{picture}	125
Likelihood ratio test					
		X^2	*df*	*p*	
Close versus unrelated	14.626	1		<.001***	
Distant versus unrelated	5.841	1		.015*	
Coding formula in R					

```
N1 in cycles 2–5 ~ Semantic Blocking * Presentation Cycle + (1 + Semantic Blocking +
   Presentation Cycle || participant) + (1 | picture)
```

Abbreviations: *CI*, confidence intervals; *SD*, standard deviation.

* $p < .05$; ***$p < .001$.

in the blocked cyclic naming paradigm with behavioral and electrophysiological indexes. Furthermore, this study tested the trade-off assumption between concurrently active processes of conceptual priming and lexical competition that may underlie the observable behavioral blocking effects when naming semantically related pictures. In the following, we start with the discussion separately for cycle 1 and cycles 2–5, for which we predicted semantic facilitation and interference, respectively. We then turn to discuss evidence of concurrent modulations of the two planning stages that appear to highly interact with each other, causing opposite effects on naming latencies across all cycles.

4.1 | Semantic facilitation and N1 in cycle 1

In cycle 1, we observed semantic facilitation in the semantically close condition. This confirms Navarrete and colleagues' previous report (2012, Experiment 1) of initial facilitation when named objects were semantically close to each other. In contrast, we found no facilitation in the semantically distant condition, which indicates that the level of semantic similarity needs to surpass some similarity threshold to induce semantic facilitation in the blocked-cyclic naming paradigm. Our findings, therefore, add to the accumulating evidence that high semantic similarity enhances semantic context effects.

Object recognition may involve perceptual as well as conceptual processes, and thus can be assumed to take place before 200 ms after stimulus onset (e.g., Thorpe et al., 1996; Tokudome & Wang, 2012; Valente et al., 2014; Vogel & Luck, 2000). We examined this early object identification process in cycle 1 by looking at the N1 component that falls in this time range (e.g., Itier & Taylor, 2004). An example of integrated processing of

TABLE 7 Linear mixed-effects model on log-transformed naming latencies in the close condition, with presentation cycle, N1, P2/N2 and their interaction as predictors

Log-transformed naming latencies (close condition)					
Fixed effects					
Predictors		Estimates	95% *CI*	*t*	*p*
(Intercept)		0.030	0.00 to 0.07	2.163	.038*
Presentation cycle		−0.061	−0.08 to −0.04	−5.431	<.001***
N1		0.002	0.00 to 0.00	4.710	<.001***
P2/N2		−0.002	−0.00 to −0.00	−6.129	<.001***
N1 × P2/N2		< 0.001	0.00 to 0.00	2.795	.005**
Cycle × N1		< −0.001	−0.00 to 0.00	−0.578	.563
Cycle × P2/N2		< −0.001	−0.00 to 0.00	−0.220	.825
N1 × P2/N2 × Cycle		< −0.001	−0.00 to 0.00	−1.678	.093
Random effects					
Groups		Variance	*SD*		
Participant					
(Intercept)		0.006	0.082		
Presentation cycle		0.001	0.041		
Picture					
(Intercept)		0.005	0.072		
Presentation cycle		0.005	0.070		
Residual		0.029	0.172		
Observations	13,943	$N_{\text{participant}}$	24	N_{picture}	125
Likelihood ratio test					
	X^2	*df*	*p*		
Presentation cycle	23.679	1	<.001***		
N1	30.430	1	<.001***		
P2/N2	59.247	1	<.001***		
N1 × P2/N2	5.006	1	.025*		

Coding formula in R

```
Log RT in close condition ~ Presentation Cycle * N1 * P2/N2 + (1 + Presentation Cycle |
   participant) + (1 + Presentation Cycle | picture)
```

Abbreviations: *CI*, confidence intervals; *SD*, standard deviation.

* *p* < .05; ** *p* < .01; ****p* < .001.

perceptual and conceptual priming is a study demonstrating that one's native language determines what one consciously perceives: Maier and Abdel Rahman (2018) found that participants distinguished better between verbally marked color contrasts than unmarked color contrasts, while participants whose native language does not distinguish between the same color contrasts did not show such boosted perception during categorization. Since perceptual and conceptual processing interact early on (e.g., Dell'Acqua et al., 2010; Lupyan & Ward, 2013; Maier & Abdel Rahman, 2018; Proverbio et al., 2007), in the present study, we do not distinguish between purely perceptual and purely conceptual identification, but instead, regard perceptual or conceptual effects as a whole that may aid identification.

The behavioral pattern of semantic facilitation was in line with the electrophysiological modulations as a larger posterior N1 was present only for the semantically close but not for the distant condition when compared to the unrelated condition. Moreover, enhanced N1 amplitudes predicted shorter naming latencies, confirming that participants benefited from conceptual priming in cycle 1. In cycle 1, participants encounter the stimuli for the first time within the main naming task and hence recognition is likely to be most difficult in

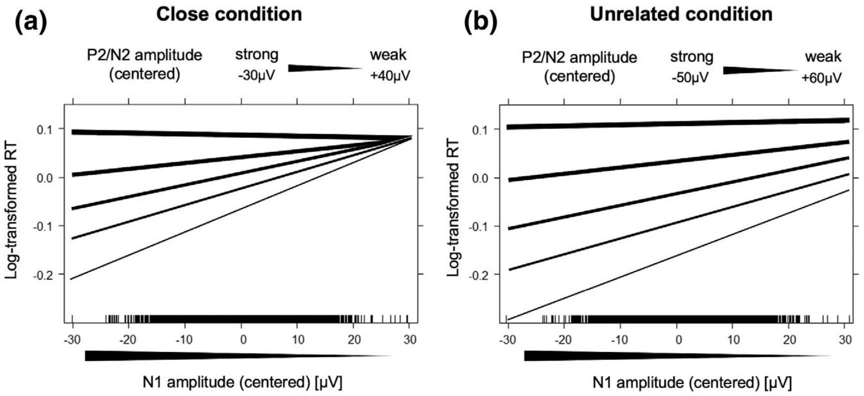

FIGURE 4 Estimated interactive modulation of N1 and P2/N2 on log-transformed naming latencies. This figure demonstrates a trade-off between the estimated N1 and P2/N2 modulations on naming latencies across all cycles in the semantically close naming condition, which is absent in the unrelated naming condition. Panel A shows the interactive modulation of N1 and P2/N2 on naming latencies in the close condition: On the one hand, the facilitatory N1 modulation is most salient when P2/N2 is weak (less negative). On the other hand, when the N1 is weak (more positive) even a weak P2/N2 yields strong inhibitory effects. Panel B shows the estimated interactive modulation of the two ERPs on naming latencies in the control analysis (unrelated condition); this interaction does not improve model fit. Both plots were initially generated using the *effect* function in the *effects* package (version 4.1-4, Fox & Weisberg, 2018) implemented in R based on the estimated effects of the LMM, and modified for better illustration of the findings

this cycle[4]. Accordingly, participants benefit from the semantic context in a top-down fashion (Abdel Rahman & Melinger, 2007; Bar et al., 2006; Scheibel & Indefrey, 2020). Furthermore, enhanced N1 amplitude is associated with objects of high inter-object similarity during object recognition learning (Tokudome & Wang, 2012). In the context of our study, larger N1 may imply reduced object recognition efforts, supporting our proposal that co-activated conceptual features from the semantically close condition facilitate object recognition, leading to facilitated naming responses in cycle 1.

4.2 | Lexical interference and P2/N2 in cycles 2–5

In cycles 2–5, a semantic interference effect emerged only for objects that were semantically close to each other. Similar to the absence of facilitation in cycle 1 in the distant condition, the absence of interference in later cycles for the distant relations again indicates a similarity threshold for the context effect to emerge. This is in line with a continuous naming study using the same pictures which demonstrated cumulative interference over ordinal naming positions exclusively with close, but not distant, relations (Rose & Abdel Rahman, 2017). Interestingly, a study using the picture-word interference paradigm to manipulate semantic similarity, again using the same pictures and relations, found significant interference in the distant condition, although they were weaker than in the close condition (Rose et al., 2019). Thus, using the same materials and semantic relations, significant interference effects in naming latencies were only found for semantically close relations in the continuous and blocked cyclic task, and interference effects were stronger for close relative to distant relations in the PWI task.

Similarly, in all picture-naming paradigms, there is converging evidence from ERPs reflecting the presence of semantic interference for semantically close but not for distant relations. Interestingly, however, the polarity of these ERPs appears to vary between paradigms. In studies using the continuous naming and PWI paradigms to test the traces of lexical interference effects, a posterior positivity is reported, starting around 200–250 ms (e.g., Costa et al., 2009; Rose & Abdel Rahman, 2017; Rose et al., 2019). In contrast, in the blocked naming paradigm used here, we find a posterior *negativity* around the same time window that is likely to reflect the lexical selection process. Indeed, a similar posterior negativity has been previously reported in other studies using this same naming paradigm (e.g., Aristei et al., 2011; Maess et al., 2002). We propose that these two posterior effects with opposite polarities in the 200–250 ms time window are analogs of one another, both reflecting lexical selection in their respective naming paradigms. This proposal is supported by the fact that the strength of the present negativity predicts naming latencies and because the time course and the posterior topographical distribution are similar in both ERP modulations.

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[4] We are aware that participants might build up a response set, storing it in working memory during the first cycle. The retrieval of the temporarily stored response set might be most helpful for closely related items, leading to the observed facilitation. This view can be well integrated with our proposal of a more beneficial semantic context aiding object recognition when naming semantically closely related pictures. However, the investigation of working memory is beyond the range of the present study.

TABLE 8 Linear mixed-effects model on log-transformed naming latencies in the unrelated condition, with presentation cycle, N1, P2/N2 and their interaction as predictors

Log-transformed naming latencies (unrelated condition)					
Fixed effects					
Predictors		Estimates	95% *CI*	*t*	*p*
(Intercept)		0.045	0.01 to 0.08	2.566	.015*
Presentation cycle		−0.185	−0.21 to −0.16	−15.027	<.001***
N1		0.001	0.00 to 0.00	4.780	<.001***
P2/N2		−0.002	−0.00 to −0.00	−6.489	<.001***
N1 × P2/N2		<0.001	−0.00 to 0.00	1.013	.311
Cycle × N1		<0.001	−0.00 to 0.00	0.644	.519
Cycle × P2/N2		−0.001	−0.00 to 0.00	−1.926	.054
N1 × P2/N2 × Cycle		<0.001	−0.00 to 0.00	0.257	.797
Random effects					
Groups		Variance	*SD*		
Participant					
(Intercept)		0.006	0.081		
Presentation cycle		0.002	0.046		
Picture					
(Intercept)		0.004	0.070		
Presentation cycle		0.006	0.077		
Residual		0.023	0.152		
Observations	13,925	$N_{participant}$	24	$N_{picture}$	125
Likelihood ratio test					
	X^2	*df*	*p*		
Presentation cycle	63.914	1	<.001***		
N1	48.154	1	<.001***		
P2/N2	101.440	1	<.001***		
N1 × P2/N2	1.848	1	.174		
Coding formula in R					

```
Log RT in unrelated condition ~ Presentation Cycle * N1 * P2/N2 + (1 + Presentation Cycle |
  participant) + (1 + Presentation Cycle | picture)
```

Abbreviations: *CI*, confidence intervals; *SD*, standard deviation.

$^{*}p < .05$; $^{***}p < .001$.

We are aware that other blocked-cyclic studies investigating the interference effects have reported a posterior positivity during the same time window, but these studies either found no correlation between the observed ERP and the blocking effects (Janssen et al., 2011) or did not report correlation tests (Wang et al., 2018). Thus, the relationship between the reported posterior positivity and the behavioral effects in these studies remains unclear. In the present study, we provide evidence for a predictive relationship between the posterior negativity and the behavioral responses in this specific paradigm. We demonstrated that stronger P2/N2 predicts longer RTs, and importantly, this posterior negativity ERP is modulated by N1 amplitude exclusively in semantically close condition. We take this as evidence of the trade-off between conceptual priming (N1 facilitatory effect) and lexical competition (P2/N2 interfering effect), whose context effects take place in parallel and become behaviorally observable when participants name categorically closely related objects. Our results therefore support the claim that the negativity found in the blocked-cyclic paradigm and the positivity found in other picture-naming paradigms essentially reflect the same underlying processes and are, quite literally, two sides of the same coin.

Although semantic interference in the blocked-cyclic paradigm typically does not accumulate over cycles, we replicate the increasing interference that has been reported before (e.g., Belke, 2008; Schnur et al., 2006, 2009). Although gradually increased semantic interference in the close condition was observed behaviorally, evidence for a correspondingly increasing N2 amplitude in the close condition was missing. A potential explanation may be that the detected effect was too weak to be captured with EEG measurement due to a noisier signal than naming latency, since the behavioral estimates of the effect of Presentation Cycle on Semantic Blocking were small (yet statistically significant). A similar speculation has been made in a PWI paradigm to explain the absence of ERP underlying the weaker yet statistically significant semantic interference in the distant condition compared with the close condition, where the ERP was significant (Rose et al., 2019).

4.3 | Concurrent conceptual priming and lexical competition

Overall, we find a pattern of initial semantic facilitation associated with an enhanced N1 amplitude in cycle 1, followed by interference, associated with a posterior negativity in the P2/N2 time range, in cycles 2–5 for the semantically close relations. Based on the theoretical assumption that semantic contexts should induce conceptual priming and lexical competition within each trial, we should find traces of lexical competition also in cycle 1 (despite overall facilitation), and we should find traces of conceptual priming also in cycles 2–5 (despite overall interference). As argued in the Swinging Lexical Network account (cf. Abdel Rahman & Melinger, 2009, 2019), net effects of semantic contexts are always composed of a trade-off between conceptual priming and lexical competition, with overall facilitation if priming dominates and overall interference if competition dominates. Indeed, for the close condition, we find an enhanced N1 amplitude (related to easier object recognition/identification) not only in cycle 1 but also in cycles 2–5. Similarly, we find an enhanced P2/N2 (taken to reflect lexical selection) not only in cycles 2–5 but also in cycle 1.[5]

Predicting naming behavior with the two ERP components, we find that stronger N1 leads to faster naming and stronger P2/N2 leads to slower naming. This holds for the related (close relation) and unrelated condition in all presentation cycles, revealing general effects of object identification/conceptualization on one hand, and lexical selection on the other. While the conceptual facilitation-related N1 and the lexical competition-related P2/N2 modulate naming latencies in parallel, crucially, their interplay determines the overall naming latencies: N1, related to object recognition, facilitates naming the most when the interfering P2/N2 is weak; when the facilitatory N1 is weak, even a weak P2/N2 yields strong interfering effects. Such a joint, interactive modulation on naming latency is exclusively observed for semantically closely related condition, but not for unrelated condition. This functionally related effect of related contexts nicely captures the trade-off assumption posited by the Swinging Lexical Network account, allowing us to dissociate how conceptual priming and lexical competition jointly affect naming behavior in different semantic contexts.

Taken together, these findings provide supporting evidence for concurrent conceptual priming (as evidenced by N1) and lexical competition (as reflected in the posterior negativity in the P2/N2 time range), in line with previous evidence on parallel processing at different speech planning stages (e.g., Abdel Rahman & Sommer, 2003; Abdel Rahman et al., 2003; Feng et al., 2021; Strijkers et al., 2017). In cycle 1, parallel to the facilitated object recognition, speakers also experience lexical competition. Presumably, the conceptual priming wins out over the lexical competition, producing a net effect that is observed as semantic facilitation. In later cycles, speakers may still profit from the context brought by the semantically close objects, while experiencing lexical competition at the same time. In these cycles, conceptual priming is less strong while lexical competition persists, which results in overall lexical interference. Although no interference was observed in later presentation cycles for the distant blocks, the N1 amplitude was still associated with naming latencies. This is another indication of the trade-off between conceptual priming and lexical competition, with the two effects canceling each other out. All in all, conceptual facilitation brought by semantic features in the distant condition does not seem to surpass the threshold for the blocking effect to emerge.

To further address the differences between close and distantly related items we applied, as an additional manipulation check, a distributional semantic model as a measure of semantic relatedness. This model computes cosine similarity between exemplars within stimuli sets and measures the frequency of the exemplars co-occurring under similar linguistic contexts based on a selected semantic space (cf. Günther

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[5] Based on the estimated coefficients, however, the effect of P2/N2 is larger in the first presentation cycle compared to the effect in cycles 2–5. We have two explanations for this: (1) Due to the nature of EEG, there might be a physiological carry-over effect; that is, a large N1 in an earlier time window in cycle 1 contributes to an enhanced amplitude of P2/N2 in a later time window. We entered N1 as a covariate into the LMMs predicting P2/N2, and vice versa, to address the concern whether these two ERPs are dependent on each other. Across all cycles, N1 and P2/N2 predicted each other to a large degree. This implies that the larger P2/N2 in the first presentation cycle seems to result from the strong activation of N1. (2) Neural-physiological response tends to be stronger at the first encounter with the stimuli and becomes weaker later on (repetition suppression). To address this concern, block order was also included as an extra covariate in the above-mentioned LMMs. Since block order does not change the semantic blocking effects, this finding indicates that the stronger amplitude of P2/N2 observed in the first presentation cycle is less likely to result from repetition suppression.

et al., 2015). Confirming our manipulation, the selected closely related items are assessed as more inter-related, compared with the distantly related items. A Pearson's correlation test showed an overall positive correlation between naming latencies and cosine similarity values in naming cycles 2–5 ($R^2 = .19$, $p < .001$). Critically, the correlation was found only in the close condition ($R^2 = .18$, $p < .001$) but not in the distant condition ($R^2 = .01$, $p = .12$). Moreover, entering cosine similarity values into the LMMs to predict naming latencies, the output shows that this predictor was only significant in the close condition (close: $\beta = 0.27$, $p < .001$; distant: $\beta = 0.11$, $p = .11$). This confirms our earlier analyses and conclusions that the influence of semantic similarity arises with sufficient semantic feature overlap. The more similar items are the stronger is the induced lexical interference.

In our design, the order of the semantic blocking conditions was counterbalanced across participants. However, due to the block-wise feature, participants might have been tacitly aware that some items were related while some were not. To ensure that the semantic blocking effects were not modulated by the order of blocking condition assignment, we entered block order as a co-variate into the original LMMs as well as its interaction with semantic blocking (the output of the analyses can be found online at OSF, link provided in the Method section). These control analyses showed that the reported effects remained robust when including block order as a co-variate. Only in the first presentation cycle, ERP effects in the distant condition seemed to be influenced by block order; since no corresponding behavioral effects were observed, we refrain from further speculation on this interaction.

4.4 | Implications on theories of lexical selection

As proposed by Oppenheim and Nozari (2021), one probably cannot distinguish between competitive and non-competitive accounts of lexical selection with the blocked-cyclic design, and we do not intend to do so in the present study. From the point of view of Oppenheim and colleagues' Dak Side model (Oppenheim et al., 2010), which does not assume direct competitive lexical selection process, their error-based incremental learning mechanism may also account for our findings in later cycles, at least behaviorally. In the case of naming related objects, the connections between concept and target lexical representation get strengthened once the target word is selected, while connections between the categorical concept and the to-be-named competitors get weakened. The learning algorithm takes into account the weight changes and operates in the upcoming trials, lowering initial activations of lexical representation of the competitors, thereby slowing down lexical selection. All in all, the lexical interference in later cycles reported here can be explained by the Dark Side model.

Nonetheless, our findings of concurrent modulations of N1 and P2/N2, do not speak to Oppenheim's learning-based account. The limitation is that we based our hypotheses on the competitive Swinging Lexical Network account, and therefore chose regions and time window of interests accordingly. Since the Dark Side model does not, to our knowledge, assume facilitatory conceptual processing, the finding of N1 in an early time window provides little insight to the model. On top of that, it is difficult to argue that the reported posterior negativity reflects both the excitatory/inhibitory connections during lexical activation and selection processes because as its amplitude grows, naming latencies clearly get slower. In short, future studies are needed to specifically target the electrophysiological traces relevant to the proposal of the Dark Side model.

To conclude, the present study demonstrates that in a blocked-cyclic naming task, speakers initially identify semantically closely related objects quicker, but are hampered in later object naming. Such effects require sufficient overlapping semantic features to emerge because semantically distantly related objects induce no behavioral differences. That is, high semantic similarity induces strong semantic context effects, with facilitated processing during first presentation and lexical interference in later presentations. The electrophysiological evidence indicates easier object recognition underlying the initial facilitation around 140–180 ms after stimulus onset, and interfering effects in the time range between 250 and 350 ms. Moreover, the N1 component and the posterior negativity in the P2/N2 time range jointly modulate behavioral responses and affect each other's strength, whether or not the context effect eventually emerges as semantic facilitation or lexical interference. These functionally related effects support the idea that there is always a trade-off between concurrent conceptual priming and lexical competition upon naming closely related objects. The current findings contribute to the accumulating literature on the influence of semantic similarity on context effects during language production, and relate the behavioral facilitatory and interfering blocking effects to ERP components that reflect different but interacting planning stages during naming in the blocked cyclic paradigm.

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CONFLICT OF INTEREST

We have no conflicts of interest to disclose.

AUTHOR CONTRIBUTIONS

Hsin-Pei Lin: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Software; Visualization; Writing – original draft. **Anna Katharina Kuhlen:** Conceptualization; Formal analysis; Investigation; Methodology; Project administration; Supervision; Writing – original draft. **Alissa Melinger:** Conceptualization; Investigation; Methodology; Writing – review & editing. **Sabrina Aristei:** Conceptualization; Investigation; Methodology; Writing – review & editing. **Rasha Abdel Rahman:** Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Writing – original draft.

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Supplemental analyses & results

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APPENDIX A.

COMPLETE LIST OF STIMULI

Tiere (animals)				
Vögel (birds)	**Fische (fish)**	**Insekten (insects)**	**Huftiere (ungulates)**	**Affen (apes)**
Adler (eagle)	Hai (shark)	Fliege (fly)	Kamel (camel)	Schimpanse (chimpanzee)
Kolibri (hummingbird)	Aal (eel)	Biene (bee)	Reh (roe deer)	Pavian (baboon)
Papagei (parrot)	Forelle (trout)	Schmetterling (butterfly)	Pferd (horse)	Gorilla (gorilla)
Geier (volture)	Rochen (ray)	Hirschkäfer (stag beetles)	Esel (donkey)	Orang-Utan (orangutan)
Eule (owl)	Lachs (salmon)	Ameise (ant)	Schaf (sheep)	Mandrill (mandrill)
Kleidung (cloth)				
Kopfbedeckung (headwear)	**Mäntel (coats)**	**Schmuck (jewelry)**	**Schuhe (shoes)**	**Unterwäsche (underwear)**
Turban (turban)	Mantel (coat)	Armreif (bracelet)	Stiefel (boot)	BH (bra)
Hut (hat)	Jacke (jacket)	Kette (chain)	Pumps (court shoe)	Tanga (thong)
Mütze (wooly hat)	Poncho (poncho)	Ohrring (earring)	Turnschuhe (gym shoe)	Socke (socks)
Cappy (cap)	Anorak (anorak)	Brosche (brooch)	Clogs (clogs)	Korsett (corset)
Zylinder (top hat)	Sakko (suit jacket)	Diadem (diadem)	Mokassins (moccasins)	Unterhemd (vest)
Lebensmittel (food)				
Obst (fruits)	**Getränke (drinks)**	**Pilze (mushrooms)**	**Kräuter (herbs)**	**Süßigkeiten (sweets)**
Apfel (apple)	Tee (tea)	Pfifferling (chanterelle)	Basilikum (basil)	Kuchen (cake)
Birne (pear)	Milch (milk)	Steinpilz (cep)	Petersilie (parsley)	Eis (ice cream)
Kirsche (cherry)	Bier (beer)	Morchel (morel)	Dill (dill)	Praline (praline)
Trauben (grapes)	Wein (wine)	Champignon (mushroom)	Schnittlauch (chives)	Bonbon (candy)
Mandarine (tangerine)	Cocktail (cocktail)	Bovist (puffball)	Rosmarin (rosemary)	Lakritze (licorice)
Möbel (furniture)				
Sitzen (sit)	**Liegemöbel (reclining furniture)**	**Aufbewahrungs möbel (storage furniture)**	**Sanitär (sanitary)**	**Textil (textile)**
Couch (couch)	Bett (bed)	Regal (shelf)	Badewanne (bathtub)	Perserteppich (Persian carpet)
Hocker (stool)	Futon (futon)	Kleiderschrank (wardrobe)	Pissoir (urinal)	Vorhang (curtain)
Ohrensessel (wing chair)	Liege (day bed)	Vitrine (showcase)	Waschbecken (sink)	Rollo (blind)

Tiere (animals)				
Vögel (birds)	**Fische (fish)**	**Insekten (insects)**	**Huftiere (ungulates)**	**Affen (apes)**
Eckbank (corner seat)	Hängematte (hammock)	Truhe (chest)	Dusche (shower)	Badvorleger (mat)
Bürostuhl (office chair)	Schlafsofa (sofa bed)	Sideboard (sideboard)	Bidet (bidet)	Tischdecke (tablecloth)
Werkzeug (tool)				
Küche (kitchen)	**Bauernhof (farm)**	**Friseur (hairdresser)**	**Arzt (doctor)**	**Büro (office)**
Schneebesen (whisk)	Pflug (plough)	Kamm (comb)	Reflexhammer (reflex hammer)	Edding (Edding pen)
Kochlöffel (spoon)	Rechen (rake)	Lockenstab (curling iron)	Spritze (syringe)	Tacker (stapler)
Nudelholz (rolling pin)	Heugabel (hay fork)	Schere (scissors)	Pinzette (tweezers)	Bleistift (pencil)
Messer (knife)	Sense (scythe)	Bürste (brush)	Akupunkturnadel (acupuncture needle)	Lineal (ruler)
Dosenöffner (can-opener)	Axt (axe)	Haarnadel (hair pin)	Thermometer (thermometer)	Klammer (staple)
Unrelated 1	**Unrelated 2**	**Unrelated 3**	**Unrelated 4**	**Unrelated 5**
Eule (owl)	Fliege (fly)	Gorilla (gorilla)	Schaf (sheep)	Lachs (salmon)
Sakko (suit jacket)	Clogs (clogs)	Hut (hat)	Jacke (jacket)	Kette (chain)
Praline (praline)	Dill (dill)	Kirsche (cherry)	Tee (tea)	Bovist (puffball)
Bett (bed)	Bidet (bidet)	Truhe (chest)	Dusche (shower)	Rollo (blind)
Kamm (comb)	Spritze (syringe)	Bürste (brush)	Bleistift (pencil)	Sense (scythe)
Unrelated 6	**Unrelated 7**	**Unrelated 8**	**Unrelated 9**	**Unrelated 10**
Adler (eagle)	Mandrill (mandrill)	Hai (shark)	Pferd (horse)	Biene (bee)
Tanga (thong)	Socke (socks)	Brosche (brooch)	Mütze (wooly hat)	Stiefel (boot)
Bonbon (candy)	Rosmarin (rosemary)	Apfel (apple)	Steinpilz (cep)	Cocktail (cocktail)
Eckbank (corner seat)	Badvorleger (mat)	Couch (couch)	Futon (futon)	Liege (day bed)
Kochlöffel (spoon)	Edding (Edding pen)	Pflug (plough)	Thermometer (thermometer)	Nudelholz (rolling pin)
Unrelated 11	**Unrelated 12**	**Unrelated 13**	**Unrelated 14**	**Unrelated 15**
Schimpanse (chimpanzee)	Ameise (ant)	Kolibri (hummingbird)	Rochen (ray)	Esel (donkey)
Ohrring (earring)	Cappy (cap)	Poncho (poncho)	Korsett (corset)	Turban (turban)
Wein (wine)	Eis (ice cream)	Morchel (morel)	Trauben (grapes)	Schnittlauch (chives)
Badewanne (bathtub)	Ohrensessel (wing chair)	Sideboard (sideboard)	Perserteppich (Persian carpet)	Vitrine (showcase)
Rechen (rake)	Pinzette (tweezers)	Dosenöffner (can-opener)	Schere (scissors)	Lineal (ruler)
Unrelated 16	**Unrelated 17**	**Unrelated 18**	**Unrelated 19**	**Unrelated 20**
Forelle (trout)	Orang-Utan (orangutan)	Geier (volture)	Hirschkäfer (stag beetles)	Kamel (camel)
Anorak (anorak)	BH (bra)	Armreif (bracelet)	Mokassins (moccasins)	Pumps (court shoe)
Lakritze (licorice)	Milch (milk)	Pfifferling (chanterelle)	Petersilie (parsley)	Mandarine (tangerine)
Pissoir (urinal)	Tischdecke (tablecloth)	Hängematte (hammock)	Regal (shelf)	Bürostuhl (office chair)
Heugabel (hay fork)	Lockenstab (curling iron)	Messer (knife)	Tacker (stapler)	Akupunkturnadel (acupuncture needle)

Tiere (animals)				
Vögel (birds)	**Fische (fish)**	**Insekten (insects)**	**Huftiere (ungulates)**	**Affen (apes)**
Unrelated 21	**Unrelated 22**	**Unrelated 23**	**Unrelated 24**	**Unrelated 25**
Reh (roe deer)	Papagei (parrot)	Pavian (baboon)	Schmetterling (butterfly)	Aal (eel)
Unterhemd (vest)	Diadem (diadem)	Turnschuhe (gym shoe)	Zylinder (top hat)	Mantel (coat)
Bier (beer)	Birne (pear)	Basilikum (basil)	Kuchen (cake)	Champignon (mushroom)
Vorhang (curtain)	Kleiderschrank (wardrobe)	Schlafsofa (sofa bed)	Hocker (stool)	Waschbecken (washbasin)
Haarnadel (hair pin)	Schneebesen (whisk)	Reflexhammer (reflex hammer)	Axt (axe)	Klammer (staple)