Hearing "Birch" Hampers Saying "Duck" –
An ERP Study on Phonological Interference
in Immediate and Delayed Word Production

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Abstract

When speakers name a picture (e.g., “duck”), a distractor word phonologically related to an alternative name (e.g., “birch” related to “bird”) slows down naming responses compared to an unrelated distractor word. This interference effect obtained with the picture-word interference (PWI) task is assumed to reflect the phonological co-activation of close semantic competitors and is critical for evaluating contemporary models of word production. In the present study, we determined the event-related brain potential (ERP) signature of this effect in an immediate and a delayed version of the PWI task. ERPs revealed a differential processing of related and unrelated distractors: an early (305 – 436 ms) and a late (537 – 713 ms) negativity for related as compared with unrelated distractors. In the behavioral data, the interference effect was only found in immediate naming, while its ERP signature was also present in delayed naming. The time window of the earlier ERP effect suggests that the behavioral interference effect indeed emerges at a phonological processing level, while the functional significance of the later ERP effect is as yet not clear. The finding of a robust ERP correlate of phonological co-activation might facilitate future research on lexical processing in word production.

Keywords: speech production, lexical access, lexical co-activation, phonological interference, picture-word interference

Introduction

Since the early beginning of experimental psychology, picture naming has been a prominent tool for the chronometric study of mental processes (see Cattell, 1885). By now, there is ample evidence for context effects in picture naming tasks and this evidence has informed contemporary models of word production. For example, a distractor stimulus that is semantic-categorically related to the picture name (e.g., the word “dog”, if the picture shows a sheep) slows down the naming response when compared to an unrelated distractor stimulus (e.g., the word “flute”). This effect has been observed with written or spoken distractor words (e.g., La Heij, 1988; Lupker, 1979; Schriefers et al., 1990), with distractor sounds (e.g., the barking sound of a dog, Mädebach, Kieseler et al., 2018; Mädebach, 2017), and with distractor pictures (e.g., the picture of a dog, Mädebach, Wöhner, & Jescheniak, 2018). This semantic interference effect is assumed to reflect competitive selection of the target word at an abstract-lexical level (e.g., Jescheniak et al., 2020; Levelt et al., 1999; Roelofs, 1992, 2018; cf. Finkbeiner & Caramazza, 2006). A phonologically related distractor stimulus also affects naming latencies, albeit differently. A distractor stimulus that is phonologically related to the picture name itself (e.g., “sheet”) speeds up the naming response (e.g., Damian & Martin, 1999; Jescheniak & Schriefers, 2001; Schriefers et al., 1990). This phonological facilitation effect is assumed to reflect the pre-activation of phonological segments to be selected, leading to an easier encoding of the target word at a phonological level. In contrast, a distractor stimulus that is phonologically related to an alternative picture name (e.g., “birch”, when “bird” is the alternative name to the target word “duck”) slows down the naming response (e.g., Jescheniak et al., 2005; Kurtz et al., 2018; Mädebach et al., 2020). This phonological interference effect is assumed to reflect the co-activation of

phonological segments of a non-target competitor word at a phonological level that must not be selected, slowing down the encoding of the target word at that level.

The existence of this phonological interference effect is of central importance in the discussion on models of word production. A first prominent study did not find such an effect with words phonologically related to a close semantic-category coordinate of the target picture name (e.g., “goal”, when “goat” is the semantic-category coordinate to the target name “sheep”; see Levelt et al., 1991). This observation was taken as support for a strictly limited activation flow with serial-discrete processing stages in the lexical system (for converging evidence see Jescheniak et al., 2003, 2005; Peterson & Savoy, 1998). In such a cognitive architecture, only a selected abstract-lexical representation is phonologically activated. Later studies, however, did find such an effect with words phonologically related to an alternative name of the target picture (e.g., Jescheniak & Schriefers, 1998; Jescheniak et al., 2005; Peterson & Savoy, 1998; see also Costa et al., 2003; Hermans et al., 1998). This later evidence was taken as support of a less constrained activation flow in the lexical system according to which also strongly co-activated non-target abstract-lexical representations are phonologically co-activated (see also Dell & O’Searghda, 1991; Goldrick, 2006; Rapp & Goldrick, 2000). One likely reason why the effect is reliably observed for alternative names but not for category coordinates is that semantic and abstract-lexical co-activation is stronger for alternative names due to the higher semantic overlap with the target and thus phonological co-activation is more likely to be detected.

The existence of any differential effect of distractors phonologically related to an alternative name would suggest that these names were phonologically co-activated. Its direction – interference rather than facilitation – moreover suggests that phonological co-activation induces some form of conflict. A competitive selection

mechanism as has been proposed for selection at the abstract-lexical level (Levelt et al., 1999; Roelofs, 1992) could explain semantic interference effects (due to increased competition at the abstract-lexical level) as well as phonological interference (due to increased competition at the word-form level). In fact, prominent competitive selection accounts assume competitive selection at the abstract-lexical level as well as during word-form encoding (Levelt et al., 1999; Roelofs, 1997). The interference effect we observed could be explained by assuming that the activation strength of a lemma is translated into the activation strength of the phonemes of its word form. The related distractor then adds further activation to some of the phonemes that must not be selected during preparation of the phonological form of the target word, rendering selection of the target phonemes more difficult than in the case of an unrelated distractor (see also Jescheniak et al., 2005; Kurtz et al., 2018; Oppermann, Jescheniak, & Schriefers, 2008).

When it comes to electrophysiological evidence, a number of studies have explored ERP correlates of semantic interference and phonological facilitation (for a review see de Zubicaray & Piai, 2019). To the best of our knowledge, however, only a single study has thus far looked at possible ERP correlates of phonological interference but did not find a specific ERP signature for this effect (Jescheniak et al., 2003). Critically, this study has looked at possible ERP correlates of effects from words phonologically related to a close semantic-category coordinate of the target picture name – for which also no effect was found in several behavioral studies.

This is where the present study ties in. It aimed at extending our knowledge about word production processes by looking at possible ERP correlates of effects from distractor words phonologically related to alternatives of a current target word during picture naming – for which behavioral studies have consistently observed phonological interference. We did not have any strong predictions about which

specific ERP effects to observe – this part of our study was largely exploratory. However, we expected the timing of possible ERP effects to provide further information about the processing level at which phonological interference arises. As stated above, the effect is interpreted as reflecting the co-activation of a non-target word at the phonological level and thus should occur in a time window indicative of phonological encoding.

There is, however, a possible alternative interpretation of the effect that relates to the processing of the auditory distractor words that have been used in the previous studies (and the present one). Contemporary models of auditory word recognition assume a parallel activation of candidate words that match with the auditory input during initial processing (for a review see Weber & Scharenborg, 2012). For example, the Cohort model of spoken word recognition (Marslen-Wilson, 1987; Marslen-Wilson & Zwitserlood, 1989) assumes that upon identification of the initial phonological segments, all word forms that start with these phonological segments are activated in the lexical system in parallel. That is, after identification of the initial phonological segments “b” and “i” (of the auditory distractor word “birch”), word forms like “birch”, “birth”, and – importantly – also “bird” become activated. It has been shown that these co-activated word forms then activate their abstract lexical representations and semantic codes (e.g., Moss et al., 1997; Zwitserlood, 1989). Consequently, there is co-activation at that level, too. Due to this co-activation at multiple levels, the phonological interference effect might arise at the abstract-lexical level rather than at a phonological level (because the distractor word “birch” [also] activates “bird” at the abstract lexical level which then competes with the target name “duck” at that level). If this account was correct, we would expect a different timing of the possible ERP correlate of the effect in focus, namely it should occur earlier, in a time window indicative of semantic processing.

To arrive at a prediction regarding the possible time-course of the ERP correlate of phonological interference in PWI, we took two steps. First, we looked at existing evidence regarding ERP correlates of semantic interference and phonological facilitation in that task. Second, we referred to a meta-analytic approach providing task-independent estimates of the time-course of semantic and phonological processing in word production.

ERP correlates of semantic interference and phonological facilitation in PWI

Several ERP studies on semantic interference in PWI have observed less negative going wave-forms in the related condition compared to the unrelated condition around 250 – 550 ms after picture onset (Blackford et al., 2012; Dell'Acqua et al., 2010, Roelofs et al., 2016; Rose et al., 2019; Zhu et al., 2015; but see Hirschfeldt et al., 2008; Piai et al., 2012). This attenuated negativity in, approximately, the N400 time-window has been related to semantic priming between target picture and distractor word, but its functional significance with regard to the behavioral semantic interference effect is still under debate (Blackford et al., 2012; Roelofs et al., 2016). A recent study by Rose et al. (2019, see also Piai et al., 2014) suggests a distinction between earlier and later ERP correlates of semantic interference with the earlier modulation (starting at around 230 ms) reflecting increased lexical competition, and later modulations (at around 350 ms) reflecting ongoing semantic priming which continues in parallel with lexical and phonological processing of the target picture. If the phonological interference effect on which we focus in the present article arises at the abstract-lexical level, it should have a similar ERP correlate as the semantic interference effect (reflecting lexical competition or semantic priming or both).

There have been only few ERP studies on phonological facilitation in PWI. Dell'Acqua et al. (2010) observed an ERP correlate between 250 – 450 ms, that is, in

the same time window in which the authors also observed a correlate of semantic interference. In contrast, Zhu et al. (2015) observed an ERP correlate of phonological facilitation between 450 – 600 ms, that is, in a later time window than the one in which they observed a correlate of semantic interference. Other studies (Blackford et al., 2012; Bürki, 2017) did not find any ERP correlate of phonological facilitation at all. In sum, existing data on electrophysiological correlates of phonological facilitation in PWI are sparse and the results have been so far inconsistent. It thus appears that clear predictions for an ERP correlate of phonological interference indicative of a genuine phonological locus of that effect cannot be derived from existing studies.

Time-course estimates for semantic and phonological processing in word production

Another way to derive predictions regarding the time-course of a possible ERP correlate of phonological interference is to resort to a meta-analysis conducted by Indefrey and Levelt (2004; for an update see Indefrey, 2011) that led to detailed time-course estimates of the subprocesses involved in word production. This meta-analysis was based on more than 80 behavioral and physiological word production studies. For simple picture naming with an overall latency of 600 ms, the model proposed by the authors suggests visual and conceptual processing to finish at around 200 ms, followed by abstract-lexical (lemma) selection (200 – 275 ms), phonological retrieval (275 – 355), syllabification (355 – 455 ms), and phonetic encoding (455 – 600 ms). Based on previous experiments with the same materials as used in the present study, we expected overall naming latencies to be longer, in the range of about 750 ms. This slowing is likely caused by the presence of distractor words which we assume to primarily affect lexical retrieval and word form encoding. Linear scaling of the duration of these specific processes to the expected overall latency of 750 ms leads to the following adjusted estimated time windows: abstract-

lexical selection (ca. 200 – 303 ms), phonological retrieval (ca. 303 – 413 ms), syllabification (ca. 413 – 551 ms), and phonetic encoding (ca. 551 – 750 ms).

Although these numbers appear very precise, they should only be considered as rough estimates of the real time-course, given the variation in processing times between participants, experimental materials, and experimental tasks. Nevertheless, the numbers provide a helpful reference for deriving predictions and interpreting a potential ERP effect and its functional significance. Specifically, if the phonological interference effect indeed arises during phonological processing, any potential ERP correlates should not occur earlier than about 300 ms.

Immediate versus delayed picture naming

Apart from identifying possible ERP correlates of phonological interference in word production, a second – methodological – aim of our study was to contrast two different task versions, immediate picture naming and delayed picture naming, respectively. In immediate naming, participants were instructed to prepare and execute a naming response as soon as a target picture was presented. In delayed naming, participants were also instructed to prepare a naming response as soon as a target picture was presented but – critically – to withhold its execution until a response cue appeared with some delay. The immediate naming task allowed us to track the ERP correlate of phonological interference under the same conditions in which also the behavioral effect is observed. One drawback of immediate naming is that artifacts from articulatory muscle movements can contaminate the ERPs which is particularly problematic the closer the cognitive processes of interest are to articulation (e.g., phonological and phonetic encoding). Delayed naming avoids this problem by separating cognitive word planning processes and articulatory muscle movements in time. However, delayed naming introduces additional processes (including the processing of the response cue) and the time-course of word planning

processes may differ from immediate naming. This makes it difficult to directly link ERP results from delayed naming on the one hand and behavioral evidence from immediate naming on the other. So far, there is only one study directly comparing immediate and delayed naming (Laganaro & Perret, 2011). This study concluded that ERPs in delayed naming deviate from those in immediate naming already after about 350-400 ms and that, thus, only immediate naming can be used to track phonological and phonetic encoding in real time.

In sum, both immediate and delayed naming may be problematic for observing an ERP correlate of the phonological interference effect if it indeed originates during phonological encoding as we hypothesize. We thus took the following measures to address these problems. To alleviate the influence of motor artifacts caused by articulatory muscle movements (in immediate naming), we employed a semi-automatic correction procedure utilizing independent component analyses (see methods below). This should allow us to observe ERP modulations closer to articulation onset than was possible in studies not using such a procedure (e.g., Blackford et al., 2012). In delayed naming, we added catch-trials (which were not present in Laganaro & Perret, 2011) in which the response cue appeared earlier than in regular (i.e., critical) trials. These catch-trials were intended to motivate participants to swiftly prepare the naming response upon presentation of the picture. Comparing performance in catch-trials and regular delayed and immediate naming trials allowed us to evaluate whether participants indeed followed the instructions. Finally, the direct comparison of immediate and delayed naming results allowed us to evaluate the robustness of the ERP findings in either task.

Predictions

With respect to the behavioral data, we predicted phonological interference to be present in immediate naming, replicating previous findings, but to be absent in

delayed naming. The reason for the latter prediction is that any process giving rise to the behavioral effect should be completed at the time at which the articulatory response is initiated if the delay between picture onset and response-cue onset is sufficiently long. This should be the case with the 1.2 s delay we used. With respect to the electrophysiological data, we predicted ERP correlates of phonological interference in both task versions. If the effect indeed arises during phonological processing, a potential ERP correlate should occur no earlier than about 300 ms after picture onset. In the following, we report all data exclusions, manipulations, and measures implemented in the study.

Method

Participants

We tested twenty-four participants, most of them students from Leipzig University (18 females, 6 males, mean age: 24.7 years, $SD = 6.0$). The sample size was determined prior to data collection based on design considerations and previous studies looking at ERP correlates of semantic and phonological effects in the PWI task. All participants were German native speakers, right-handed, had normal or corrected to normal vision, and no attested hearing deficits. They affirmed not to be pregnant, not to be under the influence of sedatives or medication affecting the central nervous system, and to have no attested neurological disorders or diseases. All participants gave informed written consent before the experiment. They either received course credit or were financially reimbursed (8 €/h). Our study and all its experimental procedures followed the principles of the Declaration of Helsinki and the ethical guidelines of the German Psychological Society (DGPs).

Materials

We used the materials from Jescheniak et al. (2017). The target pictures were color photographs of 32 common objects. They were selected based on a series of

pre-tests which ensured that their preferred names are at the subordinate level (76.6% of cases) while at the same time both subordinate and basic-level names are considered appropriate responses for them (scale 1-5 with 5 = “very appropriate”; subordinate level name $M = 5.0$; basic level name $M = 4.1$; for further details see Jescheniak et al., 2017). The set was composed of two pictures each from 16 basic-level categories. For each of these subsets of pictures, a word that shared its initial phonological segments with the category name was used to create the phonologically related distractor condition (e.g., “Foto” [photograph] for the alternative name “Vogel” [bird], when the target names were “Ente” [duck] and “Storch” [stork]). To create the corresponding unrelated distractor condition, each related distractor word was reassigned to a different (semantically, associatively, and phonologically unrelated) subset of pictures, see the Appendix for a full list of the materials. Pictures had their background removed and were sized to yield a visual angle of about $4^\circ \times 4^\circ$. Distractor words were spoken by a female native speaker of German and digitally recorded at a sampling rate of 48 kHz (duration 663 – 850 ms, $M = 761$ ms, $SD = 57$ ms). For the construction of practice and warm-up trials, 8 additional pictures and distractors were selected and prepared accordingly.

Apparatus

Visual stimuli were presented centered on a 19” CRT monitor (Iijama HM903DTA). Screen resolution was 1,024 x 768 pixel, background white (RGB 255 255 255), and viewing distance about 1.5 m. Auditory distractor words were presented with Sennheiser HD25 headphones at a comfortable listening volume. The experiment was controlled by GNU Octave and the Psychophysics Toolbox (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997), operated under Linux. Participants’ naming responses were registered with a Sennheiser K6 / ME 64 microphone and digitally recorded for a time window of 3.5 s starting from picture onset.

The EEG was recorded at a sampling rate of 512 Hz from 64 Biosemi ActiveTwo (MK2) electrodes. Electrodes were placed following the extended 10-10-system. The online reference was placed on the tip of the nose and two electrodes were placed on the mastoids for offline re-referencing. The electrooculogram (EOG) was recorded by placing four electrodes at the outer canthi and above and below the left eye.

Design

The within-participant and within-item design included the variables distractor condition (phonologically related vs. unrelated) and task (immediate vs. delayed naming). Task was blocked. For each task, there were four repetition blocks, in each of which all items appeared once with their related distractor and once with their unrelated distractor. These repetition blocks were implemented to collect a sufficiently high number of observations per experimental condition and per participant for the analysis of the electrophysiological data (up to 128 observations). Task-sequence and the sequence of distractor conditions per item across repetition blocks was counterbalanced over participants in parallel lists (i.e., with the same order of target pictures, but different orders of task and distractor conditions per item).

For each participant, half of the pictures appeared with a related and half of the pictures appeared with an unrelated distractor word first. Across repetition blocks, distractor sequence per item was systematically varied. For half the items the distractor condition sequence changed with each repetition block (related first vs. unrelated first), for the other half of the items it stayed the same. Across all participants each item appeared equally often in all possible distractor condition sequences across repetition blocks. In the delayed naming task, we interspersed the experimental trials with catch trials to ensure that participants would indeed follow the

instruction and swiftly prepare their naming response upon picture onset rather than wait for the response cue. In these catch trials the response cue appeared 600 ms after picture onset, requiring a very quick overt response. There were four catch trials per 32 experimental trials. To construct these catch trials, each experimental item was used once with its unrelated distractor. In all, each participant received 256 experimental trials in each task (32 items x 2 distractor conditions x 4 repetitions) and 32 additional catch trials (in delayed naming only).

We created 24 pseudorandomized lists using Mix (Van Casteren & Davis, 2006) with the following constraints: (a) repetitions of a picture were separated by at least eight intervening trials and (b) repetitions of a distractor word by at least one intervening trial, (c) semantically related pictures or (d) pictures whose name started with the same phonological segment were not presented in consecutive trials, (e) a given distractor condition was not repeated in more than three consecutive trials and (f) specific sequences of any two pictures in consecutive trials were not repeated.

Procedure

The experiment was conducted in the BioCog Research Laboratory at Leipzig University. First, participants received written instructions for the task they would start with and a booklet showing all pictures and their (subordinate-level) names. Participants were asked to use only these names in the experiment. For the immediate naming task, participants were instructed to name the pictures as quickly and accurately as possible. For the delayed naming task, participants were instructed to prepare the naming response as quickly as possible when a picture appears but to withhold the overt response until a response cue (“!!!”) is presented. Upon appearance of the response cue, the prepared response should be initiated as quickly and accurately as possible.

During the experiment, participants were seated in a comfortable office chair in an electrically shielded, double-walled, and dimly lit sound booth (Industrial Acoustics Company). In a first practice block, each picture was presented once. Participants performed either the immediate or the delayed naming task, depending on the task order they were assigned to. Erroneous responses were corrected. Next, participants were informed that in the following trials, spoken words would be presented together with the pictures and that they should continue to respond to the pictures only while ignoring the words. Ten practice trials (composed of practice pictures and distractors) were presented. Then, the experimental trials (and catch trials in the case of delayed naming) for the first task were presented with short pauses after each repetition block. Each repetition block started with one warmup trial (with practice picture and distractor word). Once the first task was completed, the whole procedure (with exception of the booklet-study phase) was repeated for the other task after a short break.

Target picture and auditory distractor word started simultaneously. In the experimental trials of both tasks, the picture was presented for 1 s. In the experimental trials in delayed naming, the response cue appeared 200 ms after picture offset. In the non-experimental catch trials in delayed naming, the picture was presented for only 600 ms and immediately followed by the response cue (300 ms duration). All trials lasted 4 s.

Data preprocessing

Naming latencies and naming correctness were determined offline by means of visual and auditory inspection using CheckVocal (Protopapas, 2007). Naming latencies were defined as the time elapsed between the onset of the picture (in immediate naming) or the onset of the response cue (in delayed naming) and the onset of the vocal response. Naming responses were coded as erroneous and

excluded from reaction time and ERP analyses in the case of either no response, an unexpected response, or a disfluent response. In delayed naming, trials were also excluded if the response was given before the onset of the response cue but these trials were not included in the error analysis.

The EEG data were pre-processed using EEGLAB (Delorme & Makeig, 2004). We re-referenced the data offline to the nose-electrode for data pre-processing and to the average of the mastoid electrodes for statistics and figures. Data were first filtered with a 45 Hz low-pass filter (171-point filter, transition band width = 10 Hz) and subsequently with a 0.1 Hz high-pass filter (8,449-point filter, transition band width = 0.2 Hz). Data were divided into epochs of 1 s time-locked to picture onset, including a pre-stimulus baseline of 200 ms. We excluded all epochs with signals exceeding peak-to-peak amplitudes of 1,000 μ V at any electrode. Channels were excluded if they had a robust z score of the robust standard deviation greater than 3 (Bigdely-Shamlo et al., 2015; a single channel in two participants, and two, three, and five channels in a single participant, respectively). Artifacts, including speech articulation artifacts, were corrected with an independent component analysis (ICA), using an extended infomax algorithm. For the ICA, the raw data excluding bad channels and epochs were filtered with a 45 Hz low-pass filter (171-point filter, transition band width = 10 Hz) and with a 1 Hz high-pass filter (1,691-point filter, transition band width = 1 Hz), and divided into epochs of 1 s (-200 – 800 ms to picture onset), but not baseline-corrected. Artifact independent components (ICs) were classified both using the SASICA EEGLAB plugin and manually. The criteria for artifact rejection in EEGLAB included correlation with vertical and horizontal EOG electrodes, low autocorrelation of time-course, focal channel topography, focal trial activity, residual variance, correlation with bad channels, and ADJUST and FASTER criteria (Chaumon et al., 2015; Mognon, Jovicich et al., 2011; Nolan et al., 2010). The

subsequent manual classification led to both, the additional rejection of some of the ICs accepted in EEGLAB and the inclusion of some of the ICs rejected in EEGLAB. The criteria for the manual classification of ICs included features of the topography (especially focal in contrast to widespread), peak at an alpha frequency range (8 – 12 Hz), homogeneity of all trials per IC (in terms of the temporal development of activity within each trial). Independent components related to motoric and non-motoric (e.g., tongue movement and glossokinetic potentials) effects of speech production were additionally identified by occurrence in only (the late part of) the immediate naming condition. Removal of speech articulation artifacts by means of ICA has been previously demonstrated and validated by Porcaro et al. (2015). In contrast to Porcaro and colleagues (2015), we used the extended Infomax rather than fastICA algorithm and manually rather than automatically selected artifact components for rejection under the premise to avoid as far as possible the exclusion of components potentially reflecting a neuronal contribution. Artifact IC activity was subtracted from the data. On average 19.4 ICs were removed from the data per participant (*Mdn* = 18; *min* = 11; *max* = 40). Bad channels were interpolated using spherical spline interpolation. Subsequently, data were baseline corrected using the 200 ms window before stimulus presentation. Finally, epochs with signals exceeding peak-to-peak amplitudes of 200 μ V and trials with behavioral errors were excluded. Individual average ERPs were computed per participant, task, and condition and grand average waveforms were computed from the individual average ERPs per task and condition.

Behavioral analyses

Based on the exclusion criteria (see above), 2.73 % of all experimental trials were excluded from reaction time and ERP analyses. Immediate naming and delayed naming were analyzed separately. The behavioral data were fitted to mixed effect

models treating participants and items as crossed random factors (Baayen et al., 2008). Model fit was done in R (R Core Team, 2019) using the Bayesian modeling package brms (Bürkner, 2017). All models included a fixed effect for distractor condition as well as corresponding by-participant and by-item slopes and their respective correlations with the random intercepts (i.e., the maximal random structure; Barr et al., 2013). Immediate naming latencies were fitted to a shifted lognormal distribution and delayed naming latencies to a normal distribution. The respective choice of distribution was informed by WAIC-based model comparisons between normal, lognormal, and shifted lognormal fits of the data. The apparent differences in the shape of the latency distribution in immediate and delayed naming corroborate that latencies in both tasks do not reflect the same underlying processes. Error data were fitted to a binomial (Bernoulli) distribution.

ERP analyses

Given that the ERP analysis was exploratory and no previous knowledge on the specific characteristics of a possible ERP correlate available, we preferred a data-driven analysis strategy. First, ERP data were analyzed using cluster-based permutation tests as implemented in FieldTrip (Maris & Oostenveld, 2007) implicitly controlling the family-wise error rate. Temporo-spatial clusters were defined by neighboring time-points and channels with a minimum number of 3 channels. All other parameters were kept as suggested in the Fieldtrip tutorial on cluster-based permutation tests (using two-tailed dependent samples *t*-tests for the cluster statistics). First, we tested for an interaction of distractor condition and task by comparing the related minus unrelated difference waves between tasks (as suggested by the Fieldtrip documentation). As we did not observe any interaction effects, we tested for main effects of distractor condition and task by averaging the data across task and distractor conditions, respectively.

Next, we performed a temporal principal component analysis (PCA; or exploratory factor analysis) following the guidelines by Dien (2010; 2012; Dien & Frishkoff, 2005) using the psych package in R (Revelle, 2018). Temporal PCA results in a set of component loadings and a set of component scores. The loadings reflect the strength of the association (covariation/correlation) of each variable (time point) with the underlying component and describe the time-course of the components. The scores reflect the standardized weight of the components' contribution to the observed ERP per participant, condition, and electrode location. Temporal PCA is particularly advantageous in exploratory ERP analyses as it does not depend on the canonical definition of analysis time windows and reduces the considerable bias in estimates of amplitude, latency, and location due to component overlap. The PCA was computed on the individual average ERPs for all electrode locations and conditions. The PCA component structures were highly similar if computed separately for the immediate and delayed naming tasks. We therefore computed a single PCA including both, the immediate and the delayed naming tasks to improve the PCA decomposition due to better signal-to-noise ratio. PCA was computed using Geomin rotation ($\epsilon = 0.05$; Scharf & Nestler, 2019) with a covariance relationship matrix and without normalization (but standardized/correlation loadings were used for rotation as recommended by Dien, 2005). The number of components was determined using Horn's parallel test (indicating to retain 10 components) and a scree test (indicating to retain 11 components). As it is commonly considered as more problematic to underestimate rather than to overestimate the number of components, we retained 11 components (explaining more than 98.3 % of the variance). Note that components are ordered by explained variance and not chronologically by peak latency (that is, component 2 peaks earlier than component 1).

We focused the statistical analysis on the components sensitive for the distractor condition manipulation (component 2/N3, component 1/P3, and component 3/CNV; see below). Component mean scores were computed within regions of interest (ROI; N3: F1, Fz, F2, AF3, AFz, AF4; P3: P1, Pz, P2, PO3, POz, PO4; CNV: F1, Fz, F2, FC1, FCz, FC2) per participant and condition and analyzed using repeated measures ANOVAs with the within subject factors task (immediate vs. delayed naming) and distractor condition (related vs. unrelated). An alpha-level of .05 was defined for all statistical tests and the generalized η^2_G effect size measure is reported.

Together with the ANOVA results we report amplitudes and effect sizes of the main and interaction effects including the 95 % confidence intervals of the estimates (in square brackets). We also report Bayes factors for the paired, two-tailed Bayesian *t*-tests directly corresponding to the frequentist ANOVA design main and interaction effects performed in R using the BayesFactor package (Morey and Rouder, 2018). The null hypothesis corresponded to a standardized effect size $\delta = 0$, while the alternative hypothesis was defined as a Cauchy prior distribution centered around 0 with a scaling factor of $r = 0.707$ (the default “medium” effect size prior scaling). In line with the Bayes Factor interpretation (Lee & Wagenmakers, 2013) data were taken as moderate evidence for the alternative (or null) hypothesis if the BF_{10} was greater than 3 (or lower than 0.33), while values close to 1 were considered only weakly informative. Values greater than 10 (or smaller than 0.1) were considered strong evidence for the alternative (or null) hypothesis.

Results

Behavioral measures

Table 1 displays mean naming latencies and error rates broken down by trial type and distractor condition. Responses in (delayed naming) catch trials were about

250 ms faster than those in immediate naming and about 270 ms slower than those in regular delayed naming. This pattern suggests that participants did follow the delayed naming instructions and swiftly prepared naming responses upon appearance of the picture.

Table 1

Mean naming latencies (in ms) and error rates (in %) per trial type and distractor condition. The standard error (based on participant means) is given in parentheses.

Distractor	Trial type					
	Immediate		Delayed		Delayed / catch	
Related	763 (34)	2.5 (0.6)	228 (12)	0.6 (0.2)		
Unrelated	751 (33)	1.7 (0.4)	227 (13)	0.5 (0.2)	499 (15)	1.2 (0.6)
Difference	12 (4)	0.8 (0.3)	1 (3)	0.1 (0.2)		

In immediate naming, responses were slower with related compared to unrelated distractors. This effect was estimated at 0.02, 95% CI [0.00, 0.05] on the logscale which corresponds to 12 ms, 95% CI [0, 24]. The posterior probability for longer latencies in the related condition is 97%. In delayed naming, latencies were virtually identical in both distractor conditions. The condition effect was estimated at 1 ms, 95% CI [-5, 8]. Error rates were generally very low (ca. 1.4%) and did not differ reliably between distractor conditions in either task. In summary, there was phonological interference from related distractor words in immediate naming, replicating earlier findings, but no such effect in delayed naming, in line with our predictions.

ERP measures

Grand-averaged ERP waveforms for each task and distractor condition are displayed in Figure 1. The grand average ERPs in both tasks showed the N1 and P1

component in response to the visual and auditory stimuli that only differed marginally between distractor conditions and tasks. Starting at approximately 250 ms, the data in both tasks showed enhanced negativity in the related compared to the unrelated distractor condition. The effect of distractor condition on the ERP differed only marginally between tasks.

Cluster permutation tests. Cluster-based permutation tests applied to the merged data set revealed a significant difference between the related and unrelated distractor condition. It identified two clusters ($p < .001$), one at 305–436 ms and one at 537–713 ms. The first cluster was maximal over left fronto-central sites, and included electrodes Fp1, AF7, AF3, F1, F3, F5, F7, FT7, FC5, FC3, FC1, C1, C3, C5, T7, TP7, CP5, CP3, CP1, P1, P3, P5, PO3, POz, CPz, Fpz, Fp2, AF8, AF4, Afz, Fz, F2, F4, FT8, FC6, FC4, FC2, FCz, Cz, C2, C4, C6, T8, TP8, CP6, CP4, CP2, P2, P4, P6, P8, P10, PO8, PO4, O2. The second cluster was maximal over central sites, and included electrodes Fp1, AF7, AF3, F1, F3, F5, F7, FC5, FC3, FC1, C1, C3, C5, CP3, CP1, P1, P3, P5, PO3, POz, Pz, CPz, Fpz, Fp2, AF8, AF4, Afz, Fz, F2, F4, FC4, FC2, FCz, Cz, C2, C4, C6, T8, TP8, CP6, CP4, CP2, P2, P4, P6, P8, PO8, PO4. Topographic maps of distractor condition differences for both clusters can also be seen in Figure 1 (Panel C).

Figure 1

Grand-averaged ERP waveforms at frontal (F1, Fz, F2, AF3, AFz, AF4), central (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, CP2), and parietal (P1, Pz, P2, PO3, POz, PO4) regions of interest (ROIs) for both distractor conditions and the difference between conditions, separately for immediate naming (Panel A) and delayed naming (Panel B) and the data merged over both tasks (Panel C; for merged data, cluster time windows are indicated by a grey background) and both distractor conditions (Panel D), respectively. The topographic maps display the difference between distractor conditions (Panel C) and the difference between tasks (Panel D) separately for each cluster. The shaded areas reflect 95 % confidence intervals.

Figure 2 displays the difference in ERP amplitude between distractor conditions (left panel) and tasks (right panel) over time, broken down by electrode. The transparency mask illustrates the spatio-temporal regions actually forming the

significant clusters (i.e., the cluster time window limits and channel lists reflect the *maximal* extent of the clusters). This graph further illustrates that significant distractor condition differences appeared in two separate cluster time windows, as described above. Furthermore, it shows that the amplitude of the correlate returned to baseline between the two clusters across all electrodes. Channels are sorted by channel number which causes the clusters to appear to have a scattered topography. However, as can be seen in the topographic maps in Figure 1, each cluster was formed by one continuous field on the topographic map.

Figure 2

ERP amplitudes (color map) and cluster statistics (transparency maps) for the difference between the related and unrelated distractor conditions (panel A) as well as the delayed and immediate naming conditions (panel B), displaying the difference in ERP amplitude over time, broken down by electrode. Electrode numbers, broadly, begin at left frontal sites, ascending counterclockwise, first to posterior sites and then to right frontal sites.

At the beginning of the trial, the grand average ERPs differed only marginally between tasks, as described above. A contingent negative variation (CNV) potential was observed starting at approximately 250 ms, with enhanced negativity in the delayed compared to the immediate naming task. In the analysis of task differences, cluster-based permutation tests revealed a significant main effect of task, with one cluster ($p < .001$) starting at 256 ms and including all channels. Figure 1 (Panels A

and B) displays grand-averaged ERPs per task and their difference waves (Panel D) at frontal, central, and parietal ROIs. At posterior sites, CNV was overlapped by a P3 component which was possibly enhanced for the immediate naming task. The applied cluster statistic is, however, not able to separate the two effects from each other. The electrodes in between showed a less clear pattern evoked by the mixture of the CNV and the P3 component. In line with the finding of the CNV, the topographic map (Figure 1, Panel D of the topographic maps) showed that this cluster mainly had a prototypical biphasic bilateral centro-parietal topography.

PCA analysis. Three PCA components were sensitive to condition. Time-courses and topographies of the reconstructed PCA components (loadings multiplied by *SD*; reflecting the contribution of the components to the observed ERPs in μV units; see Dien, 1998 for a formal proof and Dien, 2012 for an accessible explanation of this approach) are shown in Figure 3 together with the grand-average ERPs within the corresponding ROIs. Component loadings are shown in Figure 4 together with an illustration of the distributions of the task and distractor condition main effects and the task by distractor condition interaction effect per component as violin plots.

Component 2 came after N2 and will therefore in the following be referred to as “component 2/N3”. Component 2/N3 peaked 340 ms after stimulus onset and showed a dipolar topography with a negative maximum over frontal and positive bilateral maxima over occipital electrode locations. N3 component scores were significantly more negative in the related distractor condition compared to the unrelated distractor condition ($-0.7 [-1.11 -0.3] \mu\text{V}$; $d = -0.73 [-1.18 -0.28]$; $BF_{10} = 24.24$; $F(1,23) = 12.93$, $p = .002$, $\eta^2_G = .008$). We did not observe a statistically significant main effect of task ($-1 [-2.12 0.12] \mu\text{V}$; $d = -0.38 [-0.79 0.04]$; $BF_{10} = 0.93$; $F(1,23) = 3.42$, $p = .078$, $\eta^2_G = .016$). The data provide moderate evidence against an interaction effect of task by distractor condition ($-0.08 [-0.67 0.51] \mu\text{V}$; $d = -0.06 [-0.46$

0.34]; $BF_{10} = 0.22$; $F(1,23) = 0.08$, $p = .782$, $\eta^2_G < .001$). Accordingly, the related versus unrelated distractor condition effect had similar amplitudes and effect sizes in both task conditions (immediate naming: $-0.74 [-1.25 -0.24]$; $d = -0.62 [-1.05 -0.18]$ μV ; $BF_{10} = 7.78$; $t(23) = -3.05$, $p = .006$; delayed naming: $-0.66 [-1.16 -0.16]$; $d = -0.56 [-0.99 -0.12]$ μV ; $BF_{10} = 4.34$; $t(23) = -2.75$, $p = .011$).

PCA component 1 reflects the P3 ERP component. P3 peaked 514 ms after stimulus onset over parietal electrode locations. P3 component scores were significantly more positive in the immediate naming task compared to the delayed naming task ($-4 [-5.51 -2.49]$ μV ; $d = -1.12 [-1.62 -0.6]$; $BF_{10} = 21.56$; $F(1,23) = 29.96$, $p < .001$, $\eta^2_G = .174$) and also significantly more positive in the unrelated distractor condition compared to the related distractor condition ($-0.53 [-0.85 -0.22]$ μV ; $d = -0.72 [-1.17 -0.27]$; $BF_{10} = 1545$; $F(1,23) = 12.54$, $p = .002$, $\eta^2_G = .004$). The data provide moderate evidence against an interaction effect of task by distractor condition ($-0.19 [-0.82 0.44]$ μV ; $d = -0.13 [-0.53 0.27]$; $BF_{10} = 0.26$; $F(1,23) = 0.4$, $p = .535$, $\eta^2_G < .001$). Accordingly, the related vs. unrelated distractor condition effect had similar amplitudes and effect sizes in both task conditions (immediate naming: $-0.63 [-1.12 -0.14]$; $d = -0.54 [-0.97 -0.11]$ μV ; $BF_{10} = 3.59$; $t(23) = -2.65$, $p = .014$; delayed naming: $-0.44 [-0.83 -0.05]$; $d = -0.48 [-0.89 -0.05]$ μV ; $BF_{10} = 2.02$; $t(23) = -2.75$, $p = .011$).

PCA component 3 reflects the contingent negative variation (CNV) ERP. CNV peaked 791 ms after stimulus onset over fronto-central electrode locations. CNV component scores were significantly more negative in the delayed naming task compared to the immediate naming task ($-4.99 [-7.1 -2.88]$ μV ; $d = -0.99 [-1.48 -0.5]$; $BF_{10} = 421.3$; $F(1,23) = 23.92$, $p < .001$, $\eta^2_G = .247$) and also significantly more negative in the related distractor condition compared to the unrelated distractor condition ($-0.7 [-1.05 -0.36]$ μV ; $d = -0.87 [-1.34 -0.39]$; $BF_{10} = 104.5$; $F(1,23) = 18.2$,

$p < .001$, $\eta^2_G = .006$). The data provide evidence against rather than for an interaction effect of task by distractor condition ($-0.48 [-1.27 \ 0.31] \mu V$; $d = -0.26 [-0.66 \ 0.15]$; $BF_{10} = 0.44$; $F(1,23) = 1.6$, $p = .219$, $\eta^2_G = .001$). Numerically, we observed slightly higher amplitudes and effect sizes for the related versus unrelated distractor condition effect in the immediate naming task ($-0.95 [-1.48 \ -0.41]$; $d = -0.75 [-1.19 \ -0.29] \mu V$; $BF_{10} = 27.4$; $t(23) = -3.65$, $p = .001$) compared to the delayed naming task ($-0.46 [-0.97 \ -0.05]$; $d = -0.38 [-0.8 \ 0.03] \mu V$; $BF_{10} = 0.97$; $t(23) = -1.88$, $p = .073$). The evidence was, however, unclear.

In summary, the results of the cluster-based permutation test analysis and the PCA show converging evidence for main effects of task and distractor condition with the early cluster presumably mainly reflecting PCA component 2/N3 and the late clusters presumably reflecting P3 and CNV. No statistically significant interaction effect of task by distractor condition was observed in the cluster-based permutation test and in any of the frequentist ANOVAs. Rather, the data provide moderate evidence against a task by distractor condition interaction effect for the components 2/N3 and 1/P3.

Figure 3

Time-courses (left column, opaque lines) and topographies (right column) of the reconstructed PCA components (loadings multiplied by SD; reflecting the contribution of the components to the observed ERPs in μV units) together with the grand-average ERPs (transparent lines) within the corresponding ROIs for component 2/N2 (Panel A), P3 (Panel B), and CNV (Panel C). ROIs are highlighted in the topographies.

Figure 4

Unstandardized PCA component loadings are displayed in Panel A (scaled by SD to μ V units). Violin plots reflect the distribution of component score differences for the distractor condition main effect (green; related minus unrelated), the task main effect (blue; delayed minus immediate naming) and the distractor condition by task interaction (red) separately for component 2/N3 (Panel B; frontal ROI: F1, Fz, F2, AF3, AFz, AF4), component 1/P3 (Panel C; parietal ROI: P1, Pz, P2, PO3, POz, PO4), and component 3/CNV (Panel D; fronto-central ROI: F1, Fz, F2, FC1, FCz, FC2).

Discussion

The main aim of this study was to investigate whether a correlate of the behavioral phonological interference effect obtained in the PWI task could be found in the ERP. The ERP data indeed revealed such a correlate and thus provide further information on the nature of the effect. Before turning to the ERP correlate, we briefly discuss the behavioral data.

The behavioral data in immediate naming replicated the phonological interference effect from previous studies. It was, however, smaller and less robust than in previous studies using the same materials (Jescheniak et al., 2017; Kurtz et al., 2018; Mädebach et al., 2020). Across eight experiments reported in these studies

(with $N = 320$ participants), the phonological interference effect was estimated to be about 23 ms, 95% CI [14, 33] (for details of the calculation see Mädebach et al., 2020). The effect in the present study is at the lower end of this range. Additional analyses, including task block (first vs. second) as an additional factor, revealed that the effect was larger and more robust if immediate naming was tested first (16 ms, 95% CI [3, 29]) compared to when it was tested second, following delayed naming (7 ms, 95% CI [-8, 21]). This pattern unlikely reflects a decrease of the effect with stimulus repetition because previous data have shown that the effect is stable across many more target repetitions (Kurtz et al., 2018). We assume that there may have been some unexpected carry-over effect from delayed naming to immediate naming. Possibly, some participants, after having adjusted themselves to delayed response execution as requested by the delayed naming task instructions at the beginning of the experiment, were still slowed down in response execution to some extent when switching to immediate naming in the second part of the experiment. If so, this would have reduced the sensitivity of the latency measure in immediate naming. In line with this notion, naming latencies were indeed slower (and variance between participants higher) when immediate naming was performed in the second part of the experiment. Note that the finding of highly comparable ERP signatures of the interference effect in immediate and delayed naming does not speak against this notion, if participants had swiftly prepared the response and were only slowed down in its execution (i.e., articulation).

The behavioral data in delayed naming suggest that participants were indeed engaged in response preparation prior to the response cue. We had predicted that in delayed naming any process giving rise to the behavioral effect should be completed at the time of execution of the articulatory response, if the delay between picture onset and response-cue onset is sufficiently long. In line with this prediction, no

phonological interference effect was found in delayed naming. Catch trial performance is also informative in this regard. These trials, with a reduced response-cue delay (which was, in fact, shorter than average response latencies in immediate naming), were interspersed with the experimental delayed naming trials to encourage participants to swiftly prepare the naming response immediately after picture onset. Catch trial performance was substantially faster than immediate naming performance and slower than delayed naming performance, suggesting that their inclusion was effective. Overall, then, the behavioral data suggest that in delayed naming participants swiftly started response preparation, upon onset of the picture, and only delayed response execution, until onset of the response cue.

The ERP data revealed an effect of distractor condition with enhanced negativity in the related distractor condition. Thus, a correlate of the behavioral phonological interference effect was found. Notably, this effect did not differ between immediate and delayed naming. This observation is not trivial, for two reasons. First, this similarity presupposes that participants were engaged in the same processes in similar time windows in both task versions, despite the fact that the articulatory response was requested and executed at very different points in time relative to target picture onset (on average 757 ms and 1,429 ms after target picture onset in immediately and delayed naming, respectively). Second, the achieved ERP data quality and the highly similar ERPs observed across task versions validate that preprocessing the ERP data using ICA successfully removed artifacts caused by the articulatory muscle movements in immediate naming as previously demonstrated by Porcaro et al. (2015).

Cluster-based permutation tests of the merged data revealed that the main effect of distractor condition had two clusters, the first cluster at 305 – 436 ms that was maximal at fronto-central sites and the second cluster at 537 – 713 ms that was

maximal at central sites. The ERP amplitude of the correlate returned to baseline between the two clusters across all electrodes. This observation and the fact that both clusters have slightly different topographies strongly suggests that the two clusters represent two distinct effects. However, it does not entirely rule out the possibility that the pattern might be evoked by one continuous effect and a counteractive effect (with a similar topography and absolute amplitude, but reverse polarity) that causes the change in ERP amplitude in between the two clusters.

The PCA analysis provided converging evidence corroborating the results of the cluster-based analysis—both data driven approaches—at several levels: The PCA analysis extracted distinct components overlapping the early (component 2; N3) and the late clusters (components 1 and 3; P3 and CNV) reflecting the related versus unrelated distractor condition effect. The PCA results support our interpretation that early and late clusters presumably reflect distinct effects.

Furthermore, the clusters of the ERP correlate as well as the PCA component loadings provide detailed temporal information. Based on the estimates rescaled for the mean naming latencies expected for and obtained with the present materials, the ERP correlate of the interference effect was hypothesized to occur during word form encoding not earlier than 300 ms after picture onset (Indefrey & Levelt, 2004; Indefrey, 2011). This hypothesis was confirmed by occurrence of the first cluster in a time window of approximately 300 – 440 ms overlapping the PCA component 2/N3. Our ERP data therefore corroborate the idea that the behavioral interference effect originates during phonological processing rather than during preceding processes. The second cluster in a time window from 537 – 713 ms, however, occurred in a later time window than expected based on theoretical grounds. Its timing indicates that it appears during articulatory preparation and might, for instance, reflect response

monitoring prior to the onset of articulation. However, we do not have independent evidence for this idea and future studies are needed to address this issue.

The time-course of the early cluster and PCA component 2/N3 fits well with a phonological origin of the phonological interference effect. However, it is hard to rule out a contribution of the abstract-lexical processing level based on the time-course alone. First, in principle, our results only inform us that related distractors had an effect *no later than* the assumed time-window of phonological processing. We cannot rule out that there might be effects at earlier processing stages which the ERP may not be sensitive to. Second, the meta-analytic time-course estimates of lexical selection and word form encoding should be considered only rough approximations. It is by no means certain that – for the present task, participants, and stimuli – abstract lexical processing was completed within 300 ms, especially if one assumes that semantic-lexical and phonological processing overlap in time to some degree (e.g., Dell, 1986; Goldrick, 2006). Furthermore, ERP correlates of semantic interference in the PWI task, which likely reflect processing at the abstract lexical level, have been repeatedly found in a similar time range (i.e., 250 – 450 ms, for a review see de Zubicaray & Piai, 2019). However, semantic interference has typically been found to go along with *attenuated* negativity in the related distractor condition. This corresponds to similar findings in other tasks and has been associated with semantic priming (Blackford et al., 2012; Roelofs et al., 2016). In contrast, the effect we observed had a different polarity: there was *enhanced* negativity in the related distractor condition. This difference further supports our interpretation that the phonological interference effect does not have the same cause as the semantic interference effect (i.e., it is not reflecting semantic or abstract-lexical processing). However, it is worth noting that previous PWI studies on semantic interference and the present study do not only differ in the relation between distractor words and

target pictures. For instance, most studies on semantic interference used visual distractor words while we used auditory distractor words. Such differences may impact the time-course and polarity of the ERP effects and thus pose a limitation for the comparison of the present and previous results.

The analysis of task effects revealed one ERP cluster starting at 256 ms. The ERPs at central electrodes revealed a CNV, with enhanced negativity in delayed compared to immediate naming, reflecting the preparation for the response cue. At posterior sites, the data additionally revealed a P3 component which was enhanced in immediate naming. This interpretation was corroborated by the PCA analysis extracting P3 (component 1) and CNV (component 3) components sensitive for the task effect and temporally overlapping the corresponding cluster. The finding of a P3 component in delayed naming suggests that the processing of the picture name and the preparation of the articulatory motor program was carried out in the same way as in immediate naming. The attenuation of the P3 component in delayed naming possibly reflects that the actual execution of the naming response was carried out later than in immediate naming. Interestingly, in the early and in the later time window the modulation of the ERP was largely comparable in immediate and delayed naming. This suggests that delayed naming is not restricted to the investigation of early semantic-lexical processes in word production as proposed by Laganaro and Perret (2011; who did not include catch trials), but can also be used to study later processes (i.e., phonological and phonetic encoding) – provided that the delayed naming task promotes swift response preparation (e.g., by using catch trials).

In summary, using a PWI task, our behavioral data showed interference from distractor words phonologically related to an alternative name. This effect was obtained in immediate naming, replicating previous findings, but not delayed naming, as we predicted. The electrophysiological data revealed a robust ERP correlate of

that effect which was obtained in either task version. The observation of such an ERP correlate is novel. Its temporal signature and polarity gives support to the notion that phonological interference in the PWI task indeed emerges at a phonological level of processing. As electrophysiological studies of the PWI task have so far focused on semantic-lexical processing, with only few studies exploring phonological processes (for a review see de Zubicaray & Piai, 2019), our observation of a robust correlate of phonological interference extends the available electrophysiological data on the temporal dynamics of components of word production. It thus highlights the potential of electrophysiological studies for exploring details of word production beyond the stage of semantic-lexical processing.

The identified ERP correlate of the behavioral phonological interference effect opens up the possibility to (re-) address a number of important issues in word production research. Questions addressed with the behavioral phonological interference effect so far include the following: Is incremental learning a general mechanism in word production according to which co-activated but non-selected words become less accessible for future retrieval (Kurtz et al., 2018; Wöhner et al., 2021)? How do pragmatic constraints affect lexical activation during word production (Jescheniak et al., 2017; Mädebach et al., 2020)? To which extent does a non-target language impact word production in bilinguals (Costa et al., 2003; Hermans et al., 1998)? With respect to some of these issues, specifically adaptation and flexibility in lexical processing, recent behavioral studies unexpectedly failed to provide positive evidence. This is where the ERP correlate of phonological interference described here could come into play as a potentially more sensitive measure. Our results suggest that whether such questions are addressed with immediate or delayed naming does not matter, as long as appropriate steps (such as a sufficient number of

observations, appropriate steps in data pre-processing and artifact correction, inclusion of catch-trials in delayed naming) are taken.

Conclusion

We report a novel ERP effect that can be viewed as a neural correlate of phonological co-activation in word production. This observation extends the literature on the temporal dynamics of word production processes which so far has largely focused on early semantic-lexical processing. The identified ERP correlate of phonological processing has the potential to facilitate future research also into the later processes of word production. More generally, the present results lend further support to the notion that picture naming involves verbal encoding of multiple available candidate names which needs to be taken into consideration when using picture naming as a tool to study mental processes.

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Disclosure of interest

The authors report no conflict of interest.

Data availability statement

The behavioral data and analysis scripts to reproduce the behavioral results presented in this article are openly available via the Open Science Framework at <https://osf.io/e68cj/>. The ERP data and analysis scripts are available upon request (email to widmann@uni-leipzig.de).

References

- Baayen, R. H., Davidson, D., & Bates, D. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, 59, 390-412. <https://doi.org/10.1016/j.jml.2007.12.005>
- Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, 68, 255-278. <https://doi.org/10.1016/j.jml.2012.11.001>
- Bigdely-Shamlo, N., Mullen, T., Kothe, C., Su, K. M., & Robbins, K. A. (2015). The PREP pipeline: Standardized preprocessing for large-scale EEG analysis. *Frontiers in Neuroinformatics*, 9, 16. doi:10.3389/fninf.2015.00016
- Blackford, T., Holcomb, P. J., Grainger, J., & Kuperberg, G. R. (2012). A funny thing happened on the way to articulation: N400 attenuation despite behavioral interference in picture naming. *Cognition*, 123, 84-99. <https://doi.org/10.1016/j.cognition.2011.12.007>
- Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, 10, 433-436. doi:10.1163/156856897X00357
- Bürki, A. (2017). Electrophysiological characterization of facilitation and interference in the picture-word interference paradigm. *Psychophysiology*, 54, 1370-1392. <https://doi.org/10.1111/psyp.12885>
- Bürkner, P.-C. (2017). brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software*, 80. <https://doi.org/10.18637/jss.v080.i01>
- Cattell, J. M. (1885). The time it takes to see and name objects. *Mind*, os-XI 41, 63-65. <https://doi.org/10.1093/mind/os-XI.41.63>
- Chaumon, M., Bishop, D. V., & Busch, N. A. (2015). A practical guide to the selection of independent components of the electroencephalogram for artifact correction. *Journal of Neuroscience Methods*, 250, 47-63. <https://doi.org/10.1016/j.jneumeth.2015.02.025>
- Costa, A., Colomé, A., Gómez, O., & Sebastián-Gallés, N. (2003). Another look at cross-language competition in bilingual speech production: Lexical and phonological factors. *Bilingualism: Language and Cognition*, 6, 167 – 179. <https://doi.org/10.1017/S1366728903001111>
- Damian, M. F., & Martin, R. C. (1999). Semantic and phonological codes interact in single word production. *Journal of Experimental Psychology; Learning, Memory, and Cognition*, 25, 345-361. <https://doi.org/10.1037/0278-7393.25.2.345>

- Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review*, 93, 283-321. <https://doi.org/10.1037/0033-295X.93.3.283>
- Dell, G. S., & O'Seaghdha, P. G. (1991). Mediated and convergent lexical priming in language production: A comment on Levelt et al. (1991). *Psychological Review*, 98, 604-614. <https://doi.org/10.1037/0033-295X.98.4.604>
- Dell'Acqua, R., Sessa, P., Peressotti, F., Mulatti, C., Navarrete, E., & Grainger, J. (2010). ERP evidence for ultra-fast semantic processing in the picture-word interference paradigm. *Frontiers in Psychology*, 1, 177. <https://doi.org/10.3389/fpsyg.2010.00177>
- Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134, 9-21. <https://doi.org/10.1016/j.jneumeth.2003.10.009>
- de Zubizaray, G. I., & Piai, V. (2019). Investigating the spatial and temporal components of speech production. In G. I. de Zubizaray & N. O. Schiller (Eds.), *The Oxford handbook of neurolinguistics* (pp. 471–497). Oxford University Press. <https://doi.org/10.1093/oxfordhb/9780190672027.013.19>
- Dien, J. (1998). Addressing misallocation of variance in principal components analysis of event-related potentials. *Brain Topography*, 11, 43-55.
- Dien, J. (2010). The ERP PCA Toolkit: an open source program for advanced statistical analysis of event-related potential data. *Journal of Neuroscience Methods*, 187, 138-145. <https://doi.org/10.1016/j.jneumeth.2009.12.009>
- Dien, J. (2012). Applying principal components analysis to event-related potentials: a tutorial. *Developmental Neuropsychology*, 37, 497-517. <https://doi.org/10.1080/87565641.2012.697503>
- Dien, J., & Frishkoff, G. (2005). Introduction to principal components analysis of event-related potentials. In T. Handy (Ed.), *Event Related Potentials: A Methods Handbook*. Cambridge, Mass: MIT Press.
- Dien, J., Beal, D.J., & Berg, P. (2005). Optimizing principal components analysis of event-related potentials: Matrix type, factor loading weighting, extraction, and rotations. *Clinical Neurophysiology*, 116, 1808-1825.
- Fieldtrip documentation: How to test an interaction effect using cluster-based permutation tests? (n.d.) Retrieved from

- http://www.fieldtriptoolbox.org/faq/how_can_i_test_an_interaction_effect_using_cluster-based_permutation_tests
- Fieldtrip tutorial: Cluster-based permutation tests on event related fields. (n.d.)
Retrieved from
http://www.fieldtriptoolbox.org/tutorial/cluster_permutation_timelock
- Finkbeiner, M., & Caramazza, A. (2006). Now you see it, now you don't: on turning semantic interference into facilitation in a Stroop-like task. *Cortex*, 42, 790–796.
[https://doi.org/10.1016/S0010-9452\(08\)70419-2](https://doi.org/10.1016/S0010-9452(08)70419-2)
- Goldrick, M. (2006). Limited interaction in speech production: Chronometric, speech error, and neuropsychological evidence. *Language and Cognitive Processes*, 21, 817-855. <https://doi.org/10.1080/01690960600824112>
- Hermans, D., Bongaerts, T., de Bot, K., Schreuder, R. (1998). Producing words in a foreign language: Can speakers prevent interference from their first language? *Bilingualism: Language and Cognition*, 1, 213-229.
<https://doi.org/10.1017/S1366728998000364>
- Hirschfeld, G., Jansma, B., Bölte, J., & Zwitserlood, P. (2008). Interference and facilitation in overt speech production investigated with event-related potentials. *Neuroreport*, 19, 1227-1230. <https://doi.org/10.1097/WNR.0b013e328309ecd1>
- Indefrey, P. (2011). The spatial and temporal signatures of word production components: a critical update. *Frontiers in Psychology*, 2, 255.
<https://doi.org/10.3389/fpsyg.2011.00255>
- Indefrey, P., & Levelt, W. J. (2004). The spatial and temporal signatures of word production components. *Cognition*, 92, 101-144.
<https://doi.org/10.1016/j.cognition.2002.06.001>
- Jescheniak, J. D., & Schriefers, H. (1998). Discrete serial versus cascaded processing in lexical access in speech production: Further evidence from the coactivation of near-synonyms. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 24, 1256-1274. <https://doi.org/10.1037/0278-7393.24.5.1256>
- Jescheniak, J. D., & Schriefers, H. (2001). Priming effects from phonologically related distractors in picture-word interference. *Quarterly Journal of Experimental Psychology*, 54A, 371-382. <https://doi.org/10.1080/02724980042000273>
- Jescheniak, J. D., Hahne, A., & Schriefers, H. (2003). Information flow in the mental lexicon during speech planning: Evidence from event-related brain potentials.

- Cognitive Brain Research*, 15, 261-276. [https://doi.org/10.1016/S0926-6410\(02\)00198-2](https://doi.org/10.1016/S0926-6410(02)00198-2)
- Jescheniak, J. D., Hahne, A., Hoffmann, S., & Wagner, V. (2006). Phonological activation of category coordinates during speech planning is observable in children but not in adults: Evidence for cascaded processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 32, 373-386. <https://doi.org/10.1037/0278-7393.32.3.373>
- Jescheniak, J. D., Hantsch, A., & Schriefers, H. (2005). Context Effects on Lexical Choice and Lexical Activation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31, 905-920. <https://doi.org/10.1037/0278-7393.31.5.905>
- Jescheniak, J. D., Kurtz, F., Schriefers, H., Günther, J., Klaus, J., & Mädebach, A. (2017). Words we do not say - Context effects on the phonological activation of lexical alternatives in speech production. *Journal of Experimental Psychology: Human Perception and Performance*, 43, 1194-1206. <https://doi.org/10.1037/xhp0000352>
- Jescheniak, J. D., Wöhner, S., Bethcke, H. S., & Beaupain, M. C. (2020). Semantic interference in the picture-word interference task: Is there a pre-lexical, conceptual contribution to the effect? *Psychonomic Bulletin & Review*, 27, 373-378. <https://doi.org/10.3758/s13423-019-01667-w>
- Kleiner, M., Brainard, D., & Pelli, D. (2007). What's new in Psychtoolbox-3? *Perception*, 36, 14-14.
- Kurtz, F., Schriefers, H., Mädebach, A., & Jescheniak, J. D. (2018). Incremental learning in word production: Tracing the fate of non-selected alternative picture names. *Journal of Experimental Psychology: Human Perception and Performance*, 44, 1586-1602. <https://dx.doi.org/10.1037/xhp0000558>
- La Heij, W. (1988). Components of Stroop-like interference in picture naming. *Memory & Cognition*, 16, 400-410. <https://doi.org/10.3758/BF03214220>
- Laganaro, M., & Perret, C. (2011). Comparing electrophysiological correlates of word production in immediate and delayed naming through the analysis of word age of acquisition effects. *Brain Topography*, 24, 19-29. <https://doi.org/10.1007/s10548-010-0162-x>
- Lee, M. D., & Wagenmakers, E. J. (2014). *Bayesian cognitive modeling: A practical course*. Cambridge University Press.

- Levelt, W. J., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22, 1-75.
<https://doi.org/10.1017/S0140525X99001776>
- Levelt, W. J., Schriefers, H., Vorberg, D., Meyer, A. S., Pechmann, T., & Havinga, J. (1991). The time course of lexical access in speech production: A study of picture naming. *Psychological Review*, 98, 122-142.
<https://doi.org/10.1037/0033-295X.98.1.122>
- Lupker, S. J. (1979). Semantic nature of response competition in the picture-word interference task. *Memory & Cognition*, 7, 485-495.
<https://doi.org/10.3758/BF03198265>
- Mädebach, A., Kieseler, M.-L., & Jescheniak, J. D. (2018). Localizing semantic interference from distractor sounds in picture naming: A dual-task study. *Psychonomic Bulletin & Review*, 25, 1909-1916. <https://doi.org/10.3758/s13423-017-1386-5>
- Mädebach, A., Kurtz, F., Schriefers, H., & Jescheniak, J. D. (2020). Pragmatic constraints do not prevent the co-activation of alternative names: evidence from sequential naming tasks with one and two speakers. *Language, Cognition, and Neuroscience*, 35, 1073-1088. <https://doi.org/10.1080/23273798.2020.1727539>
- Mädebach, A., Wöhner, S., Kieseler, M.-L., & Jescheniak, J. D. (2017). Neighing, barking, and drumming horses - Object related sounds help and hinder picture naming. *Journal of Experimental Psychology: Human Perception and Performance*, 43, 1629-1646. <https://doi.org/10.1037/xhp0000415>
- Mädebach, A., Wöhner, S., & Jescheniak, J. D. (2018). Opening a file drawer - Surprisingly robust evidence for semantic interference from distractor pictures in picture naming. Poster presented at the International Workshop on Language Production 2018, Nijmegen, The Netherlands. <https://osf.io/r8d92/>
- Maris, E., & Oostenveld, R. (2007). Nonparametric statistical testing of EEG- and MEG-data. *Journal of Neuroscience Methods*, 164, 177-190.
<https://doi.org/10.1016/j.jneumeth.2007.03.024>
- Marslen-Wilson, W. D. (1987). Functional parallelism in spoken word-recognition. *Cognition*, 25, 71-102. [https://doi.org/10.1016/0010-0277\(87\)90005-9](https://doi.org/10.1016/0010-0277(87)90005-9)
- Marslen-Wilson, W., & Zwitserlood, P. (1989). Accessing spoken words – The importance of word onsets. *Journal of Experimental Psychology: Human*

- Perception and Performance*, 15, 576-585. <https://doi.org/10.1037/0096-1523.15.3.576>
- Mognon, A., Jovicich, J., Bruzzone, L., & Buiatti, M. (2011). ADJUST: An automatic EEG artifact detector based on the joint use of spatial and temporal features. *Psychophysiology*, 48, 229-240. <https://doi.org/10.1111/j.1469-8986.2010.01061.x>
- Morey, R. D., & Rouder, J. N. (2018). *BayesFactor: Computation of bayes factors for common designs* [Manual]. <https://CRAN.R-project.org/package=BayesFactor>
- Moss, H. E., McCormick, S. F., & Tyler, L. K. (1997). The time course of activation of semantic information during spoken word recognition. *Language and Cognitive Processes*, 12, 695-731. <https://doi.org/10.1080/016909697386664>
- Nolan, Whelan, & Reilly (2010). FASTER: Fully automated statistical thresholding for EEG artifact rejection. *Journal of Neuroscience Methods*, 192, 152-162. <https://doi.org/10.1016/j.jneumeth.2010.07.015>
- Oppermann, F., Jescheniak, J. D., & Schriefers, H. (2008). Conceptual coherence affects phonological activation of context objects during object naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34(3), 587–601. <https://doi.org/10.1037/0278-7393.34.3.587>
- Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, 10, 437-442. <https://doi.org/10.1163/156856897X00366>
- Peterson, R. R., & Savoy, P. (1998). Lexical selection and phonological encoding during language production: Evidence for cascaded processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 24, 539-557. <https://doi.org/10.1037/0278-7393.24.3.539>
- Piai, V., Roelofs, A., & van der Meij, R. (2012). Event-related potentials and oscillatory brain responses associated with semantic and Stroop-like interference effects in overt naming. *Brain research*, 1450, 87-101. <https://doi.org/10.1016/j.brainres.2012.02.050>
- Piai, V., Roelofs, A., Jensen, O., Schoffelen, J. M., & Bonnefond, M. (2014). Distinct patterns of brain activity characterise lexical activation and competition in spoken word production. *Plos One*, 9, e88674. <https://doi.org/10.1371/journal.pone.0088674>

- Porcaro, C., Medaglia, M. T., & Krott, A. (2015). Removing speech artifacts from electroencephalographic recordings during overt picture naming. *NeuroImage*, 105, 171–180. <https://doi.org/10.1016/j.neuroimage.2014.10.049>
- Protopapas, A. (2007). Check Vocal: A program to facilitate checking the accuracy and response time of vocal responses from DMDX. *Behavior Research Methods*, 39, 859-862. <https://doi.org/10.3758/BF03192979>
- R Core Team. (2019). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from <http://www.R-project.org>
- Rapp, B., & Goldrick, M. (2000). Discreteness and interactivity in spoken word production. *Psychological Review*, 107, 460-499. <https://doi.org/10.1037/0033-295X.107.3.460>
- Revelle, W. (2018). *psych: Procedures for Psychological, Psychometric, and Personality Research*. Northwestern University, Evanston, Illinois. R package version 1.8.12
- Roelofs, A. (1992). A spreading-activation theory of lemma retrieval in speaking. *Cognition*, 42, 107-142. [https://doi.org/10.1016/0010-0277\(92\)90041-F](https://doi.org/10.1016/0010-0277(92)90041-F)
- Roelofs, A. (1997). The WEAVER model of word-form encoding in speech production. *Cognition*, 64, 249–284. [https://doi.org/10.1016/S0010-0277\(97\)00027-9](https://doi.org/10.1016/S0010-0277(97)00027-9)
- Roelofs, A. (2018). A unified computational account of cumulative semantic, semantic blocking, and semantic distractor effects in picture naming. *Cognition*, 172, 59-72. <https://doi.org/10.1016/j.cognition.2017.12.007>
- Roelofs, A., Piai, V., Rodriguez, G. G., & Chwilla, D. J. (2016). Electrophysiology of cross-language interference and facilitation in picture naming. *Cortex*, 76, 1-16. <https://doi.org/10.1016/j.cortex.2015.12.003>
- Rose, S. B., Aristei, S., Melinger, A., & Abdel Rahman, R. (2019). The closer they are, the more they interfere: Semantic similarity of word distractors increases competition in language production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45, 753-763. <https://doi.org/10.1037/xlm0000592>
- Scharf, F., & Nestler, S. (2019). A comparison of simple structure rotation criteria in temporal exploratory factor analysis for event-related potential data. *Methodology*, 15, 43-60. <https://doi.org/10.1027/1614-2241/a000175>

- Schriefers, H., Meyer, A. S., & Levelt, W. J. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language*, 29, 86-102. [https://doi.org/10.1016/0749-596X\(90\)90011-N](https://doi.org/10.1016/0749-596X(90)90011-N)
- van Casteren, M., & Davis, M. H. (2006). Mix, a program for pseudorandomization. *Behavior Research Methods*, 38, 584-589. <https://doi.org/10.3758/BF03193889>
- Vienna, Austria: R Foundation for Statistical Computing. Retrieved from <http://www.R-project.org/>
- Weber, A., & Scharenborg, O. (2012). Models of spoken-word recognition. *Wiley Interdisciplinary Reviews – Cognitive Science*, 3, 387-401. <https://doi.org/10.1002/wcs.1178>
- Wöhner, S., Mädebach, A., Schriefers, H., & Jescheniak, J. D. (2021). Tracing changes in lexical activation during word production over repeated naming episodes with the picture-word interference task. *Manuscript in preparation*.
- Zhu, X., Damian, M. F., & Zhang, Q. (2015). Seriality of semantic and phonological processes during overt speech in Mandarin as revealed by event-related brain potentials. *Brain and Language*, 144, 16-25. <https://doi.org/10.1016/j.bandl.2015.03.007>
- Zwitserslood, P. (1989). The locus of the effects of sentential-semantic context in spoken-word processing. *Cognition*, 32, 25-64. [https://doi.org/10.1016/0010-0277\(89\)90013-9](https://doi.org/10.1016/0010-0277(89)90013-9)

Appendix

List of the experimental pictures and distractor words. English translations are given in brackets.

Target word	Alternative picture name *	Related distractor word	Unrelated distractor word
Palme [palm tree]	Baum [tree]	Bauer [farmer]	Foto [photograph]
Tanne [fir]	Baum [tree]	Bauer [farmer]	Foto [photograph]
Rose [rose]	Blume [flower]	Bluse [blouse]	Pumpe [pump]
Tulpe [tulip]	Blume [flower]	Bluse [blouse]	Pumpe [pump]
Hai [shark]	Fisch [fish]	Filter [filter]	Bauer [farmer]
Aal [eel]	Fisch [fish]	Filter [filter]	Bauer [farmer]
Jeans [jeans]	Hose [trousers]	Hobel [plane]	Nutria [nutria]
Leggings [leggings]	Hose [trousers]	Hobel [plane]	Nutria [nutria]
Dackel [dachshund]	Hund [dog]	Humpen [beaker]	Käfig [cage]
Pudel [poodle]	Hund [dog]	Humpen [beaker]	Käfig [cage]
Barbie [barbie]	Puppe [doll]	Pumpe [pump]	Karren [barrow]
Matroschka [matryoshka]	Puppe [doll]	Pumpe [pump]	Karren [barrow]
Füller [fountain pen]	Stift [pen]	Stirn [forehead]	Bluse [blouse]
Kuli [ballpoint pen]	Stift [pen]	Stirn [forehead]	Bluse [blouse]
Ente [duck]	Vogel [bird]	Foto [photograph]	Brom [bromine]
Storch [stork]	Vogel [bird]	Foto [photograph]	Brom [bromine]
Toast [toast]	Brot [bread]	Brom [bromine]	Auge [eye]
Sandwich [sandwich]	Brot [bread]	Brom [bromine]	Auge [eye]
Atlas [atlas]	Buch [book]	Bude [shack]	Stirn [forehead]
Duden [dictionary]	Buch [book]	Bude [shack]	Stirn [forehead]
Boxer [boxer]	Sportler [athlete]	Sporn [spur]	Humpen [beaker]
Golfer [golfer]	Sportler [athlete]	Sporn [spur]	Humpen [beaker]
Ass [ace]	Karte [card]	Karren [barrow]	Sporn [spur]

Joker [joker]	Karte [card]	Karren [barrow]	Sporn [spur]
Flipflop [flipflop]	Schuh [shoe]	Schule [school]	Bude [shack]
Sandale [sandal]	Schuh [shoe]	Schule [school]	Bude [shack]
Trabi [Trabant]	Auto [car]	Auge [eye]	Schule [school]
Smart [Smart]	Auto [car]	Auge [eye]	Schule [school]
Mozzarella [mozzarella]	Käse [cheese]	Käfig [cage]	Filter [filter]
Parmesan [parmesan]	Käse [cheese]	Käfig [cage]	Filter [filter]
Spaghetti [spaghetti]	Nudeln [noodles]	Nutria [nutria]	Hobel [plane]
Tortellini [tortellini]	Nudeln [noodles]	Nutria [nutria]	Hobel [plane]

Note: * Alternative picture names did not appear in the experiment, neither as target words nor as distractor words. Here, they are listed only to make the relation between a (German) target word and a (German) distractor word related to an alternative (German) picture name transparent.