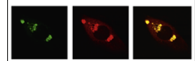


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Research Report

Distinct morphological processing of recently learned compound words: An ERP study

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ABSTRACT

Our vocabulary is, at least in principle, infinite. We can create new words combining existing ones in meaningful ways to form new linguistic expressions. The present study investigated the morphological processing of novel compound words in overt speech production. Native speakers of Dutch learned a series of new compounds (e.g. *appelgezicht*, ‘apple-face’) that were later used as primes in a morphological priming task. In this protocol, primes were compound words morphologically related to a target’s picture name (e.g. *appelgezicht* was used for a picture of an apple, Dutch *appel*). The novel primes were compared with corresponding familiar compounds sharing a free morpheme (e.g. *appelmoes*, ‘applesauce’) and with unrelated compounds. Participants were required to read aloud words and to name pictures in a long-lag design. Behavioral and event-related potentials (ERPs) data were collected in two sessions, separated by 48 h. Clear facilitation of picture naming latencies was obtained when pictures were paired with morphological related words. Notably, our results show that novel compounds have a stronger priming effect than familiar compounds in both sessions, which is expressed in a marked reduction in target naming latencies and a decrease in the N400 amplitude. These results suggest that participants focused more on the separate constituents when reading novel primes than in the case of existing compounds.

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1. Introduction

Word learning is a fundamental building block in the acquisition of language and has often been identified as one of the

distinctive components of human language (e.g. Hauser et al., 2002; Pinker and Jackendoff, 2005). Although usually associated with childhood, the addition of new words to the lexicon of an adult is a surprisingly frequent event. According to Nation

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(1997) people add about a thousand word forms per year. This translates to about three word forms per day, reflecting the fact that the mental lexicon is constantly changing. Many of the novel words we acquire are new combinations formed from already known words. An example of this productivity at the morphological level is visible in compounding, that is, the formation of regular morphologically complex words. In daily life, we are often confronted with novel compounds (e.g. Baayen and Renouf, 1996). Companies that create names for new products such as ‘powerbar’ proceed from the assumption that the constituent morphemes of these novel compounds are easily and automatically accessible to readers or listeners (Aranoff and Fudeman, 2005). Adding a word to the mental lexicon is presumably an incremental process, considering all that is potentially involved in a fully specified lexical entry. Leach and Samuel (2007) suggested there are two aspects of lexical acquisition that need to be distinguished: “lexical configuration” and “lexical engagement”. The lexical configuration is the set of factual information that one knows about a word such as the word’s sound, spelling, meaning, or syntactic feature. On the other hand, lexical engagement is the way in which a lexical entry dynamically interacts with other lexical entries (e.g., Bowers et al., 2005). In the present study, we use morphological priming in speech production as a measure of lexical engagement, performing a short and a long-term analysis (two days after learning) of this process.

Word production is generally characterized by a sequence of cognitive processes involving different types of information: conceptual preparation, lexical access, morphological encoding, phonological processing, and articulation (Levelt, 2001). There is substantial evidence that morphological structure plays a role in speech production planning (e.g., Roelofs, 1996). The long-lag morphological priming paradigm uses morphologically related prime words to precede to-be-named target pictures at a distance of several trials (Zwitserslood et al., 2000). Participants are presented with words and pictures, and are instructed to read aloud the words and to name the pictures. In this paradigm, a prime word and target picture share a free morpheme, such as pineapple and APPLE. In the Zwitserslood et al. (2000) study, a semantically related (pear – APPLE) and phonologically related condition (attic – APPLE) were included to differentiate morphological from semantic and phonological priming. They showed that only the morphologically related primes significantly diminished response times. Apparently, effects of phonological or semantic priming are short-lived whereas priming effects of free morphemes resulted in faster target naming latencies surviving at least 7–10 intervening trials. Later studies (Koester and Schiller, 2008, 2011) replicated these results in Dutch, demonstrating its robustness. Morphological priming effects were also found to survive a language switch (Lensink et al., 2014; Verdonchot et al., 2012). For instance, reading aloud the Dutch compound *tongzoen* (‘French kiss’) facilitated the naming of a picture of a tongue, even after 7–10 intervening naming trials and even when those intervening trials were in a different language (English in this case). Importantly, significant morphological priming was found for both transparent (e.g. ‘airport’) and opaque compounds (e.g. ‘butterfly’; i.e. a word for which the meaning cannot be derived from its constituents). From these, it was proposed that the facilitation effects arise at the word form level, where the

morphologically complex words and the pictures activate the same word form representation (Zwitserslood et al., 2000, 2002). Thus, the effects are suggested to be due to the morphological relation between prime and target.

A key question in language research is whether morphologically complex words are represented in the brain as whole words or in terms of their component morphemes. In language production, the question focuses on what units provide access to a word’s phonological form (Cohen-Goldberg, 2013). On the one hand, ‘full-listing’ theories (Butterworth, 1983) propose a single representation, e.g., {hotdog}, while ‘compositional’ theories argue in favor of multiple representations, e.g., {hot}+{dog} (Levelt et al., 1999; Taft and Forster, 1975). As a compromise, some models combine features from full-listing and decompositional proposals (Baayen et al., 1997; Caramazza et al., 1988; Isel et al., 2003), assuming that morphologically complex words can either be recognized via a route using morphological parsing or via a direct route accessing morphologically complex words as full forms. One of the main factors modulating the balance between parsing and full-form retrieval is the degree of familiarity of the compound. Thus, we suggest that the use of novel compounds in an overt speech morphological priming task could shed some light on this debate, as it allows analyzing the differences in the degree of priming between novel and familiar words.

Most of the previous investigations on compound word production used behavioral measures. In contrast, relatively little is known about the neuro-cognitive correlates of compound production. In Koester and Schiller (2008) and Lensink et al. (2014), using the previously mentioned morphological priming task, the N400 amplitudes were reduced for the morphologically related condition compared to the unrelated one. This corresponds to the language comprehension literature, where evidence has been found that N400 amplitudes are sensitive to morphological processing (e.g., McKinnon et al., 2003). Further evidence comes from a study using intracranial recordings within Broca’s area (Sahin et al., 2009) where participants were cued to inflect nouns and verbs. The signal was modulated by the demand of inflection at 320 ms after target word onset. The timing of these reported effects are in accordance with meta-analytic temporal estimates of morphological encoding (Indefrey and Levelt, 2004).

We propose that the long-lag morphological priming combined with ERP measures constitutes a powerful tool to further investigate the processing of newly acquired compounds. To summarize our hypothesis, if the novel words are stored in the mental lexicon after just a single learning trial, the degree of morphological priming should be the same for familiar and novel compounds. However, if there is a differential processing of recently learned compounds, it is likely that the extent of priming should differ between the familiar and the novel compounds. These differences should be expressed in the naming latencies and the ERPs components.

2. Results

2.1. Behavioral data

Mean response times for all three conditions in both sessions are shown in Fig. 1. It can be clearly seen that the unrelated

condition has slower reaction times than the related conditions in both sessions, being the novel primes the more effective in reducing naming latencies. A repeated-measures ANOVA revealed a main effect of Prime Type ($F_{1,36}=15.17$; $p<.001$; $F_{2,70}=22.64$, $p<.001$); and Session ($F_{1,17}=4.47$; $p<.05$; $F_{2,35}=61.09$; $p<.001$), and no interaction between Session and Prime ($F<1$, ns). Paired comparisons grouping both sessions together revealed that picture naming

was significantly facilitated when preceded by morphologically related primes in comparison to unrelated primes (familiar: $F_{1,17}=6.45$, $p<.05$; novel: $F_{1,17}=31.07$, $p<.0001$). In addition, the novel condition produced significantly more facilitation than the familiar one ($F_{1,17}=11.47$, $p<.01$).

2.2. ERP data

The analysis was conducted for lateral sites, divided into four different Regions of Interest (ROIs), similar to the study performed by [Lensink et al. \(2014\)](#): anterior-left (F3, FC5, C3), anterior-right (F4, FC6, C4), posterior-left (CP5, P3, PO3), and posterior-right (CP6, P4, PO4), with the factors Prime Type (3 levels: Familiar, Novel, Unrelated), Session (2 levels: Session 1, Session 2) and Region of Interest (4 levels). The mean amplitudes were evaluated for the N400 between 400 and 550 ms post stimulus onset which is similar to the time window used in written and spoken word recognition ([Kutas and Federmeier, 2011](#)).

Mean amplitude values are shown in [Fig. 2](#) (corresponding to Session 1) and [Fig. 3](#) (corresponding to Session 2). A repeated-measures ANOVA revealed a significant effect of Prime Type ($F_{2,34}=3.74$, $p<.05$), Session ($F_{1,17}=5.27$, $p<.05$)

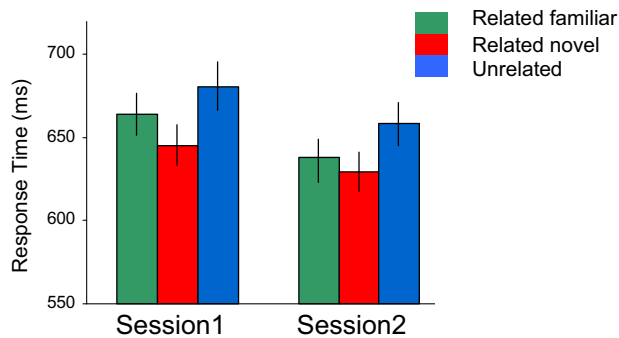


Fig. 1 – Behavioral results. Mean response times in ms (\pm standard errors) for each condition, in the first and second session.

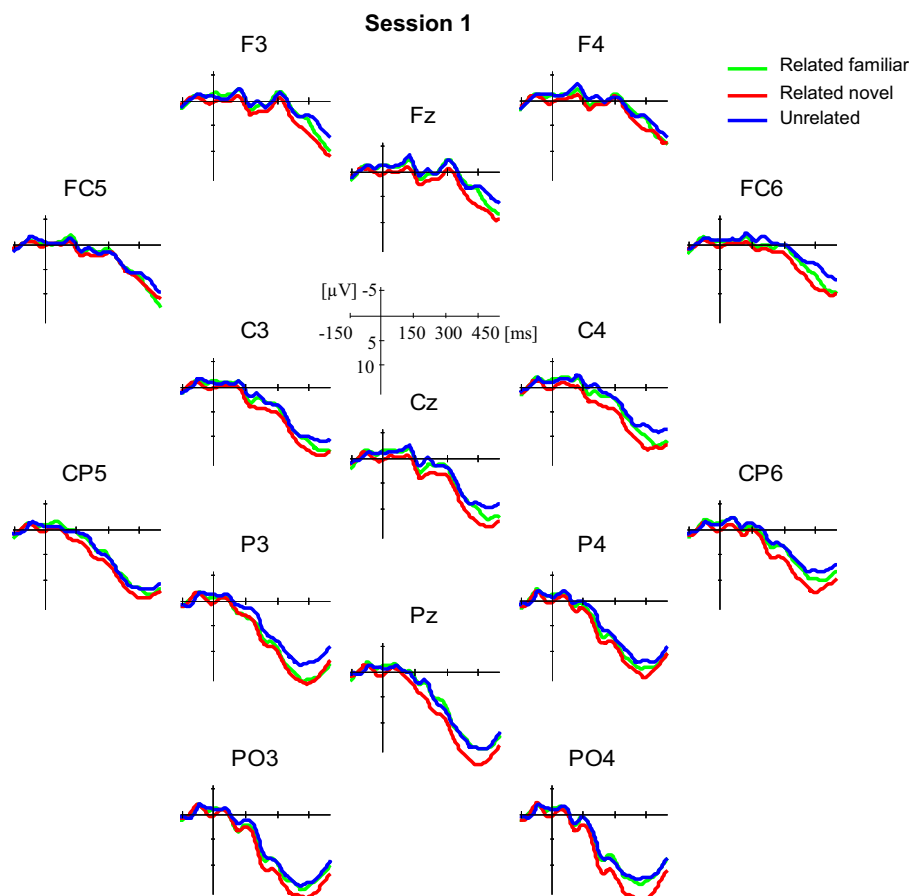


Fig. 2 – Grand average ERPs, superimposed for the morphologically related (green: Familiar, red: Novel), and the unrelated condition (blue line) in Session 1. The ERPs are time-locked to the onset of picture presentation and a 10 Hz low-pass filter was applied to smoothen the graphs. Negativity is plotted upwards.

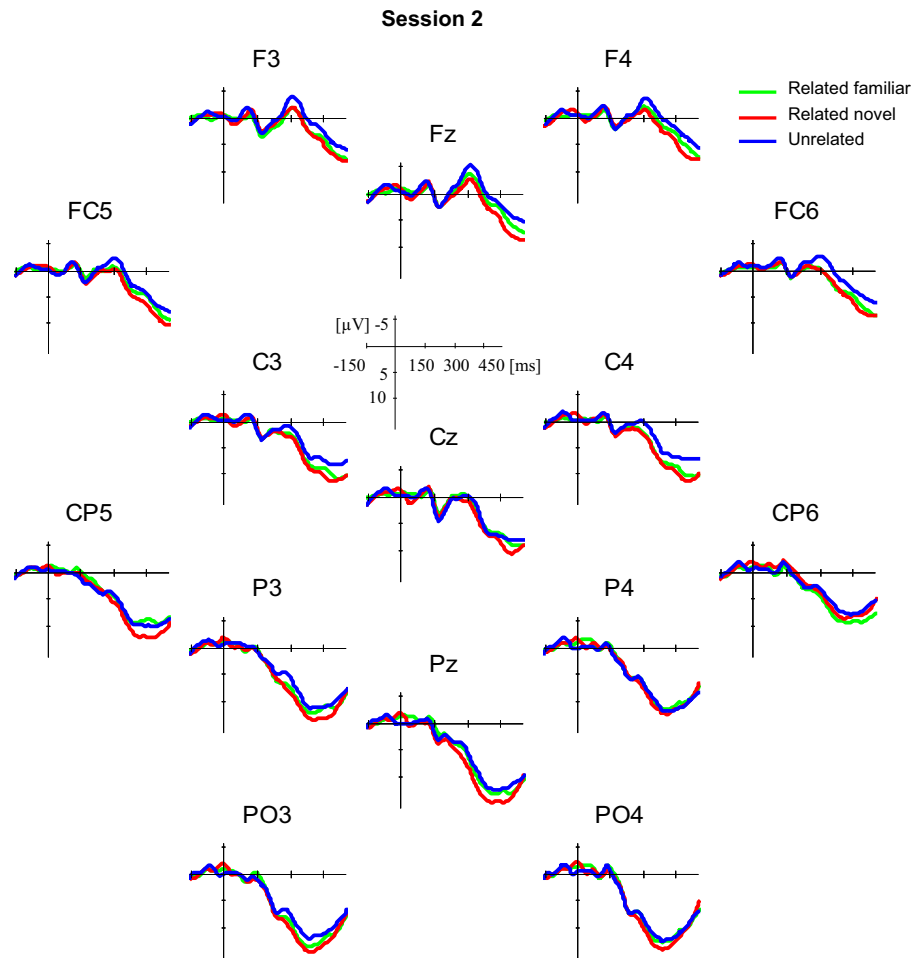


Fig. 3 – Grand average ERPs, superimposed for the morphologically related (green: Familiar, red: Novel), and the unrelated condition (blue line) in Session 2. The ERPs are time-locked to the onset of picture presentation and a 10 Hz low-pass filter was applied to smoothen the graphs. Negativity is plotted upwards.

and Region ($F_{1,53}=11.83$, $p<.01$) and no significant interaction between these factors (all $F_s<1.5$, ns).

To follow-up the significant effect of Prime Type, paired comparisons were performed between treatments. The mean ERP amplitude was reduced (i.e. less negative) for picture naming primed by novel and familiar compounds respect to the unrelated condition (planned comparisons, $F_{1,17}=10.58$, $p<.01$; $F_{1,17}=8.01$, $p<.05$, respectively). Besides, the ERP amplitude of the novel and familiar conditions reveals a marginally significant effect ($F_{1,17}=5.01$, $p=.08$).

3. Discussion

In the present study, we have analyzed morphological priming of novel compound words in overt Dutch speech production. We measured the subjects' naming latencies and ERP amplitudes when naming target pictures preceded by morphologically transparent related compounds, shortly after learning (Session 1) and two days later (Session 2). We replicated the morphological priming effect previously found by Zwitterlood et al. (2000) in German, as well as Koester and Schiller (2008, 2011) and Verdonchot et al. (2012) in Dutch and Lensink et al.

(2014) in English (L2), using familiar compound words in a similar protocol (see Schiller and Verdonchot, 2014 for an overview). Our mean RT differences between the unrelated and the related familiar condition (17 ms in session 1 and 20 ms in session 2) are in the same ballpark as the findings of Koester and Schiller (2008, 2011). Interestingly, our results reveal that newly acquired compounds strongly facilitate picture naming of related pictures, producing a larger priming effect than familiar words. This was presumably because participants focused even more on the separate constituents than in the case of existing compounds. ERP evidence is in line with the behavioral results, revealing that amplitudes in the N400 range (400–550 ms after target picture onset) were less pronounced when preceded by a novel compound, relative to a familiar one. The reduced negativity is interpreted as N400 sensitivity to morphological processing (McKinnon et al., 2003; Koester and Schiller, 2008, 2011) that is increased with novelty.

3.1. Morphological processing of novel compounds

It is worth discussing our results regarding the issue of how compound words are represented in the mental lexicon. In the early reading comprehension literature, full-listing models

proposed that compound words are processed as a single unit (e.g., {hotdog}), with no reference to its constituents (e.g., Butterworth, 1983). A similar view is provided by distributed connectionist theories, where morphological effects arise from the convergence of orthographic and semantic similarity that is commonly found in morphologically related words (Plaut and Gonnerman, 2000; Seidenberg and McClelland, 1989). However, much evidence has accumulated supporting a decompositional view (Libben et al., 1999; McKinnon et al., 2003; Taft and Forster, 1975) where complex words are processed by access to and combination of their constituent morpheme representations e.g., {hot}+{dog}. Some recent models combine features from full-listing and decompositional proposals (Baayen et al., 1997; Caramazza et al., 1988; Isel et al., 2003), assuming that morphologically complex words can either be recognized via a route using morphological parsing or via a direct route accessing morphologically complex words as full forms. Thus, very frequently used compounds (e.g., 'airport') and opaque ones (e.g., 'butterfly') are supposedly stored in their full form whereas less frequent compounds would be decomposed and their constituents' meaning needs to be combined. In a previous study using morphological priming in overt speech with existing compounds (Koester and Schiller, 2008) full-parsing and dual-route models (Badecker, 2001; Levelt et al., 1999; Taft, 2004) were proposed to account for the data, suggesting that morphemes might be planning units in language production (Roelofs, 2002).

In the present work, novel compound words were formed by combining two existing morphemes (e.g. {appel}+{gezicht}). An intriguing question is whether these new compounds are decomposed in the same way as familiar ones. Instead, it is possible to conceive that the novelty produces a differential dynamics of morphemic retrieval. Our results showed that recently learned novel compound words have a pronounced facilitation on picture naming, higher than the one found for existing compounds. A possible interpretation from these results is that novel compounds would be treated as two completely separate constituents, while familiar ones could have a mixed pattern of morphemic retrieval, in line with dual-route models (Caramazza et al., 1988). Thus, it's possible to conceive that there is more 'appel' in 'appelgezicht' (i.e., the novel compound) than in 'appelmoes' (the familiar compound). If that is the case, the distinction between full-listing and full-parsing could include a certain gradation depending on the integration of these novel words into the mental lexicon. Alternatively, novelty could cause an increase in the attentional resources devoted to the task of reading out loud the new compounds, which could contribute to a more effective decomposition of their constituents.

3.2. Electrophysiological analysis of morphological priming

Language production research has recently begun to examine the time course of various processing stages from an electrophysiological perspective (reviewed in Ganushchak et al., 2011; Piai et al., 2015). In Koester and Schiller (2008), using morphological priming in overt speech, ERPs were used to test more directly whether morphological priming originates at the word form level. They report an onset of the N400 effect that is similar to the estimated onset of morphological encoding

proposed by Indefrey and Levelt (2004) but not with other processing stages such as conceptual preparation or lemma retrieval. Thus, the effects were taken as support for the paradigm's potential to trace morphological information processing in language production (i.e. the first sub-stage of word form encoding). In addition, the N400 effect has been found to be sensitive to morphological processing in visual word recognition/comprehension (McKinnon et al., 2003). ERP results obtained in the present study are consistent with the ones obtained in Koester and Schiller (2008) and Lensink et al. (2014), as an increased amplitude value was found for morphologically primed target words in the latency range 400–550 ms post-stimulus. Although the topography of the reported effect is not the typical N400 centroparietal distribution, it coincides with the spatial distribution reported in studies using a similar picture-naming task (e.g., Ganis et al., 1996; Blackford et al., 2012; Chauncey et al., 2009). According to claims by Piai et al. (2015), there might be systematic speech-related artifacts in the ERP signal when response times differ consistently between experimental conditions. To exclude the possibility that our data could be accounted for by this explanation we carried out a correlation analysis between the response times and the mean amplitude values (in the 400–550 ms time window, combining all ROIs and conditions). If the RT differences accounted for the ERP modulation effect, a significant negative correlation between these two variables is expected. However, our results did not support this interpretation, showing a positive correlation in the first session and no significant correlation in the second one [Session 1: $r=0.53$, $p<.05$; Session 2, $r=0.32$, $p=.18$]. This analysis showed that the ERP modulation in this case would not derive from the differences in response times, but instead from the experimental priming conditions.

In both sessions, ERP amplitudes were most reduced for the related-novel condition, consistent with the behavioral results. Results revealed a Novel<Familiar<Unrelated ERP amplitude pattern, similarly to the pattern obtained in naming latencies. Importantly, the time course of the priming effect for novel compounds is coincident with the one obtained for familiar words, thus suggesting that that similar brain processes are involved in both cases.

3.3. Memory in novel word lexicalization

Previous studies investigated the dynamics of new word learning by tracing the effects of these new representations on the processing of phonologically similar existing words (Gaskell and Dumay, 2003). They showed that participants rapidly become familiar with fictitious words presented auditorily, such as 'cathedruke', whereas an engagement in lexical competition on existing words (e.g., slowed identification of the competitor 'cathedral') is only observed after a delay (Dumay and Gaskell, 2007). In addition, a study by Qiao and Forster (2013) demonstrated masked priming only for new words learned across four interspersed training sessions, and not after a single session. These previous studies support the idea that a functional incorporation of a novel word to the lexicon needs some time to develop, probably involving memory stabilization processes. However, this idea seems to be contradicted by a number of studies reporting a series of fast occurring word-like effects. For instance, a study of De







Condition	PRIME	filler	filler	filler	filler	filler	filler	filler	TARGET
	1	2	3	4	5	6	7	8	9
Related familiar	<i>appelmoes</i> (applesauce)								
Related Novel	<i>appelgezicht</i> (apple face)	<word>	<word>		<word>	<word>	<word>		
Unrelated	<i>bloedworst</i> (black pudding)								

Fig. 4 – An example of a long-lag prime-target sequence, showing the three experimental conditions and seven intervening trials, either words or pictures.

Vaan et al. (2007) provided experimental evidence that novel Dutch transparent compounds may leave traces in lexical memory after their very first occurrence, measured by a visual lexical decision task and that they last for at least one week (De Vaan et al., 2011). Mestres-Misse et al. (2007) found an N400 effect for very recently acquired words, coincidentally with Borovsky et al. (2010). Takashima et al. (2014) showed lexical competition shortly after learning novel form-only words and fMRI analysis revealed involvement of phonological lexical processing areas immediately after training, suggesting that tight connections were formed between novel words and existing lexical entries already at encoding.

In the present study, taking into account that behavioral and ERPs results reveal differences between novel and familiar words two days after learning, it is suggested that the assembly of both constituents is still incomplete. Thus, considering that the systems consolidation take a long time to develop (McClelland et al., 1995) it is possible that 48 h is still not enough time to fully assimilate the novel word in the neocortical memory systems. Alternatively, it might be the case that an extensive training regime would be necessary to incorporate the novel words to the mental lexicon.

To sum up, we demonstrated that morphological priming effects in overt speech production still hold for recently learned compound words. The priming effect for the novel compounds was even stronger than for existing compounds. This was presumably because participants focused even more on the separate constituents than in the case of existing compounds. The ERPs reflected those morphological priming effects revealing a decrease in the N400 amplitude that is reduced for novel compounds in both sessions.

4. Experimental procedure

4.1. Participants

Twenty-two right-handed native speakers of Dutch (19–25 years old, 70% females), currently enrolled in higher education or with a graduate degree, took part in the experiment in exchange for credits or a small financial reward. All participants had normal or corrected-to-normal visual acuity. All participants gave informed consent before starting the experiment. Four participants were excluded due to excessive movement artifacts or technical failures.

Table 1 – Stimulus characteristics. Frequency of occurrence — per one million; begin of overlap in syllable position.

	# of syllables	Frequency	# of phonemes	Word length	Begin of overlap
Targets	1.3	73	3.9	4.58	n/a
Primes					
Related	2.6	2.7	7.5	9.05	1.4
familiar					
Related	2.8	n/a	8.1	9.58	1.4
novel					
Unrelated	2.5	2.3	8	9.36	n/a

4.2. Materials

The target stimulus set consisted of 36 black-and-white line drawings of concrete objects. Stimuli were largely similar to Koester and Schiller (2008) and Verdonschot et al. (2012). Target pictures were preceded by compound prime words from three prime types: related-familiar, related-novel and unrelated (listed in the Appendix). The novel compounds were created by the combination of two free morphemes (constituents). An invented definition was also provided in the first phase of the experiment. These novel compounds are designed to be semantically transparent, as well as the familiar ones. For example, the picture of an apple (*appel* in Dutch) was paired with the compound *appelmoes* (applesauce) in the familiar condition or with the compound *appelgezicht* (apple face) in the novel condition (Fig. 4). Notably, both words had the same phonological and morphological overlap with the picture name, but one of the words was recently acquired, whereas the other one is already established in the mental lexicon. The target morpheme was in the word-initial or word-final position (distributed equally across conditions). The number of syllables, word frequency, number of phonemes and word length were controlled for (Table 1).

Seven or eight intervening trials were included between the prime and the target (long-lag design, see Fig. 4). It was previously demonstrated that morphological priming effects survive lags between 7 and 10 intervening trials (Koester and Schiller, 2008, 2011; Zwitserlood et al., 2000, 2002). Thus, we included 200 filler words and 50 filler pictures to allow for the creation of the intervening trials. To make the purpose less transparent, we changed the position of the pictures through trials.

4.3. Experimental procedure

Participants were tested in two sessions separated by two days. Behavioral and EEG data were acquired in both

sessions. The experiment was conducted in a soundproof booth, using a voice-key (SR-BOX) to measure the naming latencies. The experiment was designed and controlled using E-prime 2.0 (Psychology Software Tools). Session 1 had two parts: a learning phase and a priming task, while Session 2 only included the priming task. Participants received a different randomization of stimuli in each session.

In the learning phase, participants initially read from a computer screen a series of novel compounds (with invented definitions). For example, they read a word ‘appelgezicht’ (*apple face*), and then a definition ‘it’s an apple-shaped face’. They are instructed to read them one at a time, at their own pace, and to pay attention to each of the presented words, not specifying that they should learn or memorize the words. After this, they read from the computer screen the list of familiar compounds that were to be used later in the priming task. The rationale for this initial presentation of all stimuli was to standardize the exposure of all the stimuli that were to be used later in the priming task.

The procedure of the morphological priming task was similar to [Verdonschot et al. \(2012\)](#) and [Koester and Schiller’s \(2008, 2011\)](#); adapted from [Dohmes et al., 2004](#). Participants were given 5 min to familiarize themselves with the pictures and their corresponding names by studying a booklet. After this, a practice block was administered to familiarize the participants with the procedure and to assess whether the voice-key was adjusted optimally. Each trial began with the presentation of a fixation cross for 250 ms, followed by a blank screen for 250 ms. Next, the stimulus, either a word or a picture, was presented in the center of the screen (in black on a white background). Participants were instructed to name the pictures and read out loud the words that appeared on the screen as quickly and accurately as possible. Each stimulus stayed on the screen until the participant made a vocal response, for a maximum of 1400 ms, followed by an ITI of 500 ms. The experimenter assessed the validity of the trial online, indicating whether word errors or voice-key errors occurred. Subsequently, all experimental stimuli were presented in nine blocks, with short breaks in between. No feedback was provided during the experiment.

Three experimental lists were created. In each list, each target was present once. Thus, each participant only saw a particular target picture three times throughout the task, each time preceded by a different prime word (i.e., 3×36 target trials per participant over all blocks). The lists were randomized, and the filler words and pictures were varied. Furthermore, intervening trials did not contain any items phonologically or semantically related to the target picture.

4.4. EEG recordings

The electroencephalogram (EEG) was recorded using 32 Ag/AgCl electrodes (BioSemi Active Two) which were placed on the standard scalp sites of the extended international 10/20 system. Six electrodes of the flat type were used to measure the eye blinks (above and underneath the left eye), horizontal eye movements (at the external canthi of both eyes), and two were placed at the mastoids. BioSemi system uses an active electrode (CMS) and a passive electrode (DRL) to form a feedback loop that drives the average potential of the system

as close as possible to the reference voltage in the analog-digital box (see www.biosemi.com). EEG signal processing and ERP analysis were carried out with EEGLAB software ([Delorme and Makeig, 2004](#)). The EEG signal was re-referenced off-line using the mean of the two mastoids. The EEG signal was sampled at 256 Hz, and off-line band-pass filtered from 0.1 to 30 Hz (using the ‘eegfilt’ function, EEGLAB). Epochs were considered from 200 ms before the target to 550 ms after it, and the first 200 ms were used as baseline. Automatic rejection was used to exclude all epochs containing artifacts. Trials with amplitudes below $-200 \mu\text{V}$, above $+200 \mu\text{V}$, or trials that made a $100 \mu\text{V}$ or larger voltage step within 200 ms were removed from the analysis. As a consequence, 67% of the 108 trials entered the averaging procedure. Different experimental conditions were similarly affected (first session: 67.77%, 65.70% and 66.53%, second session: 68.1%, 65.2% and 67.7%, for the related familiar condition, the related novel condition and unrelated condition, respectively). The majority of the rejected trials were excluded due to movement artifacts (e.g. premature verbal responses and eye blinks). Importantly, a comparison between the behavioral effects corresponding to the remaining trials and the results obtained with all trials did not yield significant differences (t-test, first session: $t_{16} = -.26$, $p = .39$; $t_{16} = -.37$, $p = .35$; $t_{16} = -.158$, $p = .44$; second session: $t_{16} = -.12$, $p = .39$; $t_{16} = -.022$, $p = .41$; $t_{16} = -.18$, $p = .43$, for the related familiar condition, the related novel condition and unrelated condition, respectively). ERP grand averages were calculated including all epochs across all participants.

4.5. Data analyses

Mean picture naming latencies were submitted to by-participant (F1) and by-item (F2) repeated measurement ANOVAs with the factors Prime Type (related-familiar, related-novel, unrelated) and Session (session 1, session 2). Reaction times that deviated more than 2.5 SDs from the mean per participant per condition (5%) were excluded from the analyses. Participant errors (3%) were excluded from further analysis. Original degrees of freedom and Greenhouse–Geisser corrected p-values are reported.

For the EEG analysis, mean amplitude ERPs were calculated separately for each participant and each condition in relation to a 200 ms pre-stimulus baseline. Repeated-measures ANOVAs with Greenhouse–Geisser corrections were used to analyze the ERP amplitudes. Based on the findings of previous studies with a similar experimental design ([Koester and Schiller, 2008, 2011](#), [Verdonschot et al., 2012](#); [Lensink et al., 2014](#)), a basic prediction of our analysis is that a significant difference should be disclosed between morphologically related and unrelated conditions, both behaviorally and electrophysiologically. Based on this prediction, results in all cases were analyzed using a priori planned comparisons ([Rosenthal and Rosnow, 1985](#)).

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Appendix. Experimental stimuli

TARGET	Familiar prime	Novel prime	Definition	Unrelated prime
appel (apple)	appelmoes (apple sauce)	appelgezicht	Apple-looking face	aardbeiveld (strawberry field)
been (leg)	beenwarmers (leg warmer)	beenzeep	Soap for legs	aardkorst (crustal)
beer (bear)	ijsbeer (polar bear)	kajakbeer	Kayak for bears	aktetas (briefcase)
boek (book)	adresboek (directory)	boekvacht	Enclosure for books	barman (bartender)
boot (boat)	roeiboot (rowing boat)	bootpad	Path for boats	bergtop (mountain top)
boter (butter)	roomboter (dairy butter)	botervinger	Slippery finger	bivakmuts (forage cap)
broek (trouser)	zwembroek (swimming trunks)	schrijfbroek	Pants to write	blokfluit (recorder)
brug (bridge)	loopbrug (gangway)	brughark	Rake for bridges	borstvoeding (breastfeeding)
kasteel (castle)	kasteelheer (lord of the castle)	glijbaankasteel	Castle with slides	brandstof (fuel)
diamant (diamond)	diamantmijn (diamond mine)	diamantoog	Diamond eye	briefpost (letter)
ekster (magpie)	eksternest (magpie nest)	eksterolie	Oil for magpies	brillenglas (lens)
ezel (donkey)	pakezel (pack donkey)	ezelletter	Letter carried by donkeys	broodbakker (bread baker)
goud (gold)	bladgoud (gold leaf)	sigagoud	Dark gold	bushalte (bus stop)
hand (hand)	handdoek (hand towel)	pompoenhand	Orange hand	dakterras (roof)
hond (dog)	waakhond (watchdog)	hondtoon	Dog accent	dansvloer (dancefloor)
jas (jacket)	jaszak (jacket pocket)	jasgom	Eraser for jackets	deurklink (heck)
kaas (cheese)	kaasschaaf (cheese slicer)	bruidkaas	Cheese for brides	haarknipper (hair clipper)
kalkoen (turkey)	kalkoenvlees (turkey meat)	kalkoentafel	Table for turkeys	havenhoofd (jetty)
kast (closet)	koelkast (refrigerator)	wolkkast	Closet for clouds	hersenschim (chimera)
kers (cherry)	kersenpit (cherry bone)	bierkers	Cherry-tasting beer	hooiwagen (daddy longlegs)
kikker (frog)	kikkerdril (frog spawn)	kikkertapijt	Carpet made of frogs	kruidnagel (clove)
klok (clock)	kerkklok (church bell)	kloppen	Pen with a clock	kunstgebit (denture)
mes (knife)	messenslijper (grinder)	computermes	Knife for computers	mierenhoop (anthill)
muis (mouse)	veldmuis (mouse vole)	matrasmuis	Mattress living mouse	planteneter (herbivore)
neus (nose)	neusgat (nostril)	eineus	Egg-looking nose	proeftijd (probation)
konijn (rabbit)	konijnfokker (rabbit breeder)	traankonijn	Rabbit that cries a lot	rugwervel (vertebra)
sla (lettuce)	slakom (salad bowl)	ringsla	Lettuce with a hole	schoonzus (sister)
spijker (nail)	spijkerbed (bed of nails)	spijkervrouw	Very thin woman	spaargeld (savings)
ster (star)	morgenster (morning star)	sterrenkachel	Heater for stars	sportdag (sports day)
stoel (chair)	rolstoel (wheelchair)	kamstoel	Chair used when combing	sprinkhaan (grasshopper)
vlinder (butterfly)	nachtvlinder (moth)	vlindergesp	Buckle similar to a butterfly	stormwind (whirlwind)
voet (foot)	voetstap (footstep)	voetsjaal	Scarf for the feet	straatfeest (street party)
vos (fox)	vossenhol (foxhole)	vossenbril	Glasses for foxes	tentzeil (canvas)
worst (sausage)	bloedworst (black pudding)	worstboom	Tree where sausages grow	tomatensap (tomato juice)
zak (bag)	rugzak (backpack)	raketzak	Bag for missiles	vakschool (vocational school)
zon (sun)	zonlicht (sunlight)	honingzon	Honey sun	vloerkleed (carpet)

REFERENCES

- Aranoff, M., Fudeman, K., 2005. What is Morphology?. Blackwell, Oxford.
- Baayen, R.H., Renouf, A., 1996. Chronicling the times: productive lexical innovations in an English newspaper. *Language* 72, 69–96.
- Baayen, R.H., Dijkstra, T., Schreuder, R., 1997. Singulars and plurals in Dutch: evidence for a parallel dual route model. *J. Mem. Lang.* 37, 94–117.
- Badecker, W., 2001. Lexical composition and the production of compounds: evidence from errors in naming. *Lang. Cogn. Process.* 16, 337–366.
- 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.
- Borovsky, A., Kutas, M., Elman, J., 2010. Learning to use words: event-related potentials index single-shot contextual word learning. *Cognition* 116, 289–296.
- Bowers, J.S., Davis, C.J., Hanley, D.A., 2005. Interfering neighbours: the impact of novel word learning on the identification of visually similar words. *Cognition* 97, 45–54.
- Butterworth, B., 1983. Lexical representation. In: Butterworth, B. (Ed.), *Language Production*, vol. 2. Academic Press, London, pp. 257–294.
- Caramazza, A., Laudanna, A., Romani, C., 1988. Lexical access and inflectional morphology. *Cognition* 28, 297–332.
- Chauncey, K., Holcomb, P.J., Grainger, J., 2009. Primed picture naming within and across languages: an ERP investigation. *Cogn. Affect. Behav. Neurosci.* 9, 286–303.

- Cohen-Goldberg, A.M., 2013. Towards a theory of multimorphemic word production: the heterogeneity of processing hypothesis. *Lang. Cogn. Process.* 28, 1036–1064.
- Delorme, A., Makeig, S., 2004. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J. Neurosci. Methods* 134, 9–21.
- De Vaan, L., Ernestus, M., Schreuder, R., 2011. The lifespan of lexical traces for novel morphologically complex words. *Men. Lexicon* 6, 374–392.
- De Vaan, L., Schreuder, R., Baayen, R.H., 2007. Regular morphologically complex neologisms leave detectable traces in the mental lexicon. *Men. Lexicon* 2, 1–23.
- Dohmes, P., Zwitserlood, P., Bölte, J., 2004. The impact of semantic transparency of morphologically complex words on picture naming. *Brain Lang.* 90, 203–212.
- Dumay, N., Gaskell, M.G., 2007. Sleep-associated changes in the mental representation of spoken words. *Psychol. Sci.* 18, 35–39.
- Ganis, G., Kutas, M., Sereno, M.I.J., 1996. The search for "common sense": an electrophysiological study of the comprehension of words and pictures in reading. *Cogn. Neurosci.* 8, 89–106.
- Ganushchak, L.Y., Christoffels, I.K., Schiller, N.O., 2011. The use of electroencephalography in language production research: a review. *Front. Psychol.* 2, 208.
- Gaskell, M.G., Dumay, N., 2003. Lexical competition and the acquisition of novel words. *Cognition* 89, 105–132.
- Hauser, M.D., Chomsky, N., Fitch, W.T., 2002. The faculty of language: what is it, who has it, and how did it evolve?. *Science* 298, 1569–1579.
- Indefrey, P., Levelt, W.J.M., 2004. The spatial and temporal signatures of word production components. *Cognition* 92, 101–144.
- Isel, F., Gunter, T.C., Friederici, A.D., 2003. Prosody-assisted head-driven access to spoken German compounds. *J. Exp. Psychol. Learn. Mem. Cogn.* 29 (2), 277–288.
- Koester, D., Schiller, N.O., 2008. Morphological priming in overt language production: electrophysiological evidence from Dutch. *Neuroimage* 42, 1622–1630.
- Koester, D., Schiller, N.O., 2011. The functional neuroanatomy of morphology in language production. *Neuroimage* 55, 732–741.
- Kutas, M., Federmeier, K.D., 2011. Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). *Annu. Rev. Psychol.* 62, 621–647.
- Leach, L., Samuel, A.G., 2007. Lexical configuration and lexical engagement: when adults learn new words. *Cogn. Psychol.* 55, 306–353.
- Levelt, W.J., 2001. Spoken word production: a theory of lexical access. *Proc. Natl. Acad. Sci. USA* 98, 13464–13471.
- Levelt, W.J., Roelofs, A., Meyer, A.S., 1999. A theory of lexical access in speech production. *Behav. Brain Sci.* 22, 1–75.
- Lensink, S.E., Verdonschot, R.G., Schiller, N.O., 2014. Morphological priming during language switching: an ERP study. *Front. Hum. Neurosci.* 8, 995.
- Libben, G., Derwing, B.L., de Almeida, R.G., 1999. Ambiguous novel compounds and models of morphological parsing. *Brain Lang.* 68, 378–386.
- McClelland, J.L., McNaughton, B.L., O'Reilly, R.C., 1995. Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. *Psychol. Rev.* 102, 419–457.
- McKinnon, R., Allen, M., Osterhout, L., 2003. Morphological decomposition involving non-productive morphemes: ERP evidence. *Neuroreport* 14, 883–886.
- Mestres-Misse, A., Rodriguez-Fornells, A., Münte, T.F., 2007. Watching the brain during meaning acquisition. *Cereb. Cortex* 17, 1858–1866.
- Nation, I.S.P., 1997. Vocabulary size, text coverage, and word lists. In: McCarthy, S. (Ed.), *Vocabulary: Description, Acquisition and Pedagogy*. Cambridge University Press, Cambridge.
- Piai, V., Riès, S.K., Knight, R.T., 2015. The electrophysiology of language production: what could be improved. *Front. Psychol.* 5, 5160.
- Pinker, S., Jackendoff, R., 2005. The faculty of language: what's special about it?. *Cognition* 95, 201–236.
- Plaut, D.C., Gonnerman, L.M., 2000. Are non-semantic morphological effects incompatible with a distributed connectionist approach to lexical processing?. *Lang. Cogn. Process.* 15, 445–485.
- Qiao, X., Forster, K.I., 2013. Novel word lexicalization and the prime lexicality effect. *J. Exp. Psychol. Learn. Mem. Cogn.* 39, 1064–1074.
- Roelofs, A., 1996. Serial order in planning the production of successive morphemes of a word. *J. Mem. Lang.* 35, 854–876.
- Roelofs, A., 2002. Spoken language planning and the initiation of articulation. *Q. J. Exp. Psychol. A* 55, 465–483.
- Rosenthal, R., Rosnow, R., 1985. *Contrast Analysis Focused Comparisons in the Analysis of Variance*. Cambridge University Press, Cambridge, UK.
- Sahin, N.T., Pinker, S., Cash, S.S., Schomer, D., Halgren, E., 2009. Sequential processing of lexical, grammatical, and phonological information within Broca's area. *Science* 326, 445–449.
- Schiller, N.O., Verdonschot, R.G., 2014. Accessing words from the mental lexicon. In: Taylor, J.R. (Ed.), *The Oxford Handbook of the Word*. Oxford University Press, Oxford.
- Seidenberg, M.S., McClelland, J.L., 1989. A distributed, developmental model of word recognition and naming. *Psychol. Rev.* 96, 523–568.
- Taft, M., 2004. Morphological decomposition and the reverse base frequency effect. *Q. J. Exp. Psychol.* 57A, 745–765.
- Taft, M., Forster, K.I., 1975. Lexical storage and retrieval of prefixed words. *J. Verbal Learn. Verbal Behav.* 14, 638–647.
- Takashima, A., Bakker, I., van Hell, J.G., Janzen, G., McQueen, J.M., 2014. Richness of information about novel words influences how episodic and semantic memory networks interact during lexicalization. *Neuroimage* 84, 265–278.
- Verdonschot, R.G., Middelburg, R., Lensink, S.E., Schiller, N.O., 2012. Morphological priming survives a language switch. *Cognition* 124, 343–349.
- Zwitserlood, P., Bölte, J., Dohmes, P., 2000. Morphological effects on speech production: evidence from picture naming. *Lang. Cogn. Process.* 15, 563–591.
- Zwitserlood, P., Bölte, J., Dohmes, P., 2002. Where and how morphologically complex words interplay with naming pictures. *Brain Lang.* 81, 358–367.