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Koester, D.; Schiller, N.O.

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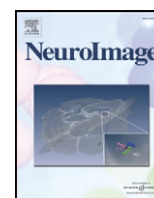
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## Morphological priming in overt language production: Electrophysiological evidence from Dutch

Dirk Koester<sup>a,b,\*</sup>, Niels O. Schiller<sup>a</sup>

<sup>a</sup> Leiden Institute of Brain and Cognition, and Leiden University, Institute for Psychological Research, The Netherlands

<sup>b</sup> F.C. Donders Centre for Cognitive Neuroimaging and Radboud University, Nijmegen, The Netherlands

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### ABSTRACT

The present study investigated morphological priming in Dutch and its time course in overt speech production using a long-lag priming paradigm. Prime words were compounds that were morphologically related to a picture name (e.g. the word *jaszak*, 'coat pocket' was used for a picture of a coat; Dutch *jas*) or form-related monomorphemic words (e.g. *jasmijn*, 'jasmine'). The morphologically related compounds could be semantically transparent (e.g. *eksternest*, 'magpie nest') or opaque (e.g. *eksteroog*, lit. 'magpie eye', 'corn', for a picture of a magpie, Dutch *ekster*). Behavioral and event-related potential (ERP) data were collected in two sessions. The production of morphologically related and complex words facilitated subsequent picture naming and elicited a reduced N400 compared with unrelated prime words. The effects did not differ for transparent and opaque relations. Mere form overlap between a prime word and a target picture name did not affect picture naming. These results extend previous findings from German to another language and demonstrate the feasibility of measuring cognitive ERP components during overt speech. Furthermore, the results suggest that morphological priming in language production cannot be reduced to semantic and phonological processing. The time course of these priming effects as reflected in the ERP measure is in accordance with a meta-analytic temporal estimate of morphological encoding in speaking [Indefrey, P., & Levelt, W.J.M. (2004). The spatial and temporal signatures of word production components. *Cognition*, 92, 101–144.] suggesting that morphological relations are encoded at the word form level.

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### Introduction

Human communication requires numerous, distinct expressions to convey our thoughts. Our vocabulary, i.e. the mental lexicon, is supposed to contain these expressions and it is at least in principle infinite. We can create new words – if necessary – because words are – to a large extent – arbitrary sound-meaning mappings, but it is also possible to combine existing words and even parts of words in meaningful ways to form new linguistic expressions. Theories of morphology describe the formation of words, i.e. their internal structure. However, up to date, there is no agreement on the brain's signature of morphological processing. In particular, little is known about the electrophysiological correlates of morphological processes, especially in language production. In the present study, we investigated morphological effects in overt language production and its time course using behavioral (i.e. reaction times) and electrophysiological measures of these lexical processes.

In contrast to language production, morphological priming has received much attention in language comprehension. Without attempting to review this literature exhaustively, some behavioral effects led to the suggestion that morphological decomposition is a rather late process relative to lexical identification, i.e. morphological information becomes available after whole-word representations have been activated (Greber and Frauenfelder, 1999; Girardo and Grainger, 2000, 2001; Zwitserlood, 2004). Other behavioral studies and the use of event-related potentials (ERPs) have questioned this theoretical view (e.g. Longtin et al., 2003; Rastle et al., 2004; Barber et al., 2002; Domínguez et al., 2004; Lavric et al., 2007).

These latter studies provide evidence for an early morphological decomposition process during visual word recognition (cf. Taft and Forster, 1975). For example, Lavric et al. (2007) reported comparable priming effects for pairs of words that were morphologically related (e.g. cleaner – clean) and pairs that only superficially had a morphological relation (e.g. corner – corn). The effects for word pairs with a mere form relation (e.g. brothel – broth; -EL is not an English suffix) were not comparable to the effects of (real or superficial) morphological relations. This result led to the conclusion that written words are morphologically decomposed irrespective of their real morphological structure. Interestingly, the morphological

\* Corresponding author. F.C. Donders Centre for Cognitive Neuroimaging, P.O. Box 9101, 6500 HB Nijmegen, The Netherlands. Fax: +31 024 36 10 98 9.

E-mail address: [d.koester@fcdonders.ru.nl](mailto:d.koester@fcdonders.ru.nl) (D. Koester).

overlap affected the N400 component in the ERP related to ease of lexical–semantic integration of the words (see also Barber et al., 2002; Domínguez et al., 2004; but Morris et al., 2007 for graded effects of semantics). Recent investigations of the functional neuro-anatomical correlates of morphological decomposition in visual word recognition also reported evidence consistent with morphological decomposition during early stages of visual word processing (Devlin et al., 2004; Gold and Rastle, 2007).

The present study is not concerned with comprehension, but with language production. Language production is generally characterized by a sequence of cognitive processes involving different types of information. The four major stages are conceptual preparation, lexical access, phonological processing, and articulation (Caramazza, 1997; Dell, 1986; Garrett, 1988; Levelt, 1989; Levelt et al., 1999). During speaking – for example when naming a picture – the conceptual representation of the intended object is activated. This activation spreads to lexical representations of these concepts. From there, phonological information is retrieved (word form encoding) that is finally used for articulation by invoking the corresponding gestural scores. However, details of this architecture, e.g. whether the activation flow is cascading or involving discrete stages is still debated (Damian and Bowers, 2003; Morsella and Miozzo, 2002; Navarrete and Costa, 2005; Jescheniak et al., 2002 vs. Levelt, 2001; Roelofs, 2003).

Different morphological mechanisms have been investigated in language production. Most behavioral research focused on the processing of inflections (Schriefers et al., 1992), verb-particle constructions (Schriefers et al., 1991; Roelofs, 1998), gender marking using free vs. bound morphemes (Lemhöfer et al., 2006; Schiller and Costa, 2006), and derivations (Schriefers et al., 1992; Zwitserlood et al., 2000). The current study aims to contribute to the research on compound word production.

Compounds are combinations of free morphemes (here called constituents) whereby most compounds are internally structured. One constituent has a distinguished status in that it determines the compound's syntactic category and usually its semantic class (the so-called *head*; Selkirk, 1982; Di Sciullo and Williams, 1987). Compounding is in principle a recursive mechanism, i.e. compounded words can be used to create another compound. For example, *birthday* (BIRTH + DAY) can be concatenated with *CAKE* to form *birthday cake*. Semantically transparent compounds such as *birthday cake* are usually distinguished from semantically opaque compounds which are not related to the meaning of their constituents (e.g. *wild-goose chase*; Sandra, 1990; Zwitserlood, 1994). Languages also differ with respect to whether their compounds are left- or right-headed. Dutch, the language under investigation, as well as English and German, is right-headed regarding compound words (Booij, 2002; Fabb, 2001).

The production of words is assumed to be prepared serially. Especially morphologically complex words have been suggested to be prepared incrementally from left to right (Roelofs, 1996; Roelofs and Baayen, 2002). For instance, Roelofs (1996) compared the production latencies of sets of words that were homogeneous regarding their initial syllable (e.g. *bijbel*, *bijna*, *bijster*; 'bible', 'almost', 'loss') with sets of words that were heterogeneous (e.g. *bijbel*, *hersens*, *nader*; 'bible', 'brain', 'further'; the so-called preparation paradigm). The phonological overlap resulted in a facilitation of 30 ms in homogenous sets. However, if the initial syllables also constituted morphemes (e.g. *Bij* in *bijvak*, *bijrol*, *bijnier*; 'subsidiary subject', 'supporting role', 'kidney'), the facilitation was significantly larger; homogeneous sets were now produced 74 ms faster than heterogeneous ones. In contrast, non-initial morphemes in homogeneous sets (e.g. *BOOM* in *stamboom*, *spoorboom*, *hefboom*; 'pedigree', 'barrier', 'lever') did not lead to a significant preparation effect. Roelofs (1996) concluded that morphemes are a planning unit in the production process and that language production proceeds incrementally from left to right.

The separate access of morphemes is suggestive of decomposed preparation of compound words (Levelt et al., 1999; Caramazza et al., 1988; Taft and Forster, 1976). That is, compounds do not have to be stored and accessed as whole units. This conception is in accordance with linear frequency effects of the constituents but not of the whole compound; higher constituent frequency is associated with shorter naming latencies (Bien et al., 2005).

The error analysis of aphasic patients' compound production also supports the decompositional view. Misproductions were found to be morpheme-based, i.e. errors such as constituent substitutions decreased with decreasing transparency and increasing frequency of the constituents (Blanken, 2000; see also Badecker, 2001; Hittmair-Delazer et al., 1994; but Bi et al., 2007).

Most of these investigations on compound production used behavioral measures. In contrast, relatively little is known about the neurocognitive correlates of compound production. Neurocognitive measures such as the electroencephalogram (EEG, as the basis for event-related potentials, ERPs) and the magnetoencephalogram (MEG) have proven useful in testing (and confirming) decompositional processes of compound comprehension in the visual and auditory modality (Fiorentino and Poeppel, 2007; Koester et al., 2007; see also Koester et al., 2004; Krott et al., 2006). Of particular interest here is an ERP study that investigated effects of morphological decomposition in word reading by McKinnon et al. (2003). These authors compared the ERPs in response to words consisting of bound morphemes (e.g. *RE-CEIVE*), non-words containing no real morphemes (e.g. \**FLERMUF*), and, critically, non-words consisting of bound morphemes (e.g. \**IN-CEIVE*). As expected, a reduced N400 amplitude was observed for words compared to unconcatenated non-words (e.g. \**flermuf*). This reduction was interpreted as a standard effect of lexical status. Importantly, concatenated morphemes that result in non-words (e.g. \**inceive*) elicited also a reduced N400 amplitude that was comparable to the one elicited by words. McKinnon et al. (2003) concluded that the N400 is not only sensitive to lexical status per se but also to morphological decomposition.

In contrast to reaction times (RTs), ERPs with their high temporal resolution can trace cognitive processes more directly before or even without an overt response (Kutas and Van Petten, 1994). Therefore, ERPs are particularly valuable for investigating the time course of cognitive processes. The limited use of electrophysiological measures in language production may result in part from two methodological issues. Firstly, overt speech can result in movement artifacts. Secondly, the interpretation of particular effects in the widely used picture-word interference paradigm is sometimes ambiguous as to whether the effects are associated with processes of production or comprehension, i.e. processing the distractor word.

These issues have been addressed differently. To avoid movement artifacts, the overt response can be delayed in ERP studies (e.g. Jescheniak et al., 2002). Strictly speaking, such a procedure restricts the interpretation to preparation processes which might not be identical to overt speech production. Alternatively, one may use a different experimental task to avoid an overt vocal response, e.g. phoneme detection or go/no-go tasks (e.g. Jansma and Schiller, 2004; Schiller, 2006; Schmitt et al., 2000, 2001). An interesting solution to the second issue emerges from work by Zwitserlood et al. (2000), especially with regard to morphology.

Zwitserlood et al. (2000) investigated morphological effects in language production by comparing the standard, immediate picture-word interference paradigm with a delayed variant. In the delayed variant, the prime word (termed "distractor" in the standard picture-word interference paradigm) preceded the target picture by 7–10 trials. Prime words were read aloud and pictures were named overtly. That is, in any trial only one stimulus is presented to the participant and, consequently, effects during picture naming are not conflated with the reading of prime words. Hence, the delayed variant of the picture-word interference paradigm can be combined profitably with

ERP measurements to investigate the electrophysiological correlates of language production.

Importantly, in the delayed paradigm, picture naming was facilitated by some 30 ms when a morphologically related complex prime word preceded the picture by 7–10 trials (Zwitzerlood et al., 2000; see also Feldman, 2000). This facilitation could not be explained by semantic or phonological form overlap between prime words and target pictures. When the same pictures were paired with semantic or phonological primes, inhibition and facilitation effects, respectively, were observed in the immediate but not in the delayed variant of the paradigm (Zwitzerlood et al., 2000). That is, in contrast to morphological effects, semantic and phonological effects are suggested to be short-lived and not effective after seven or more intervening trials. Subsequent experiments suggested that similar facilitation effects result from a morphological relation of the picture name with derivations and compound words irrespective of the position or the related morpheme (prefix vs. suffix; initial vs. head constituent; Zwitzerlood et al., 2002). 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 whereas the respective representations are distinct at the conceptual and lemma level (Zwitzerlood et al., 2000, 2002).

ERPs can be used to test more directly whether morphological priming originates at the word form level by investigating the time course of morphological priming effects. Regarding this time course, a meta-analytic review of the literature suggests that these effects should be present around 330 ms after picture onset assuming an average picture naming latency of 600 ms (Indefrey and Levelt, 2004). Naturally, morphological priming should affect morphological encoding, the first process during word form encoding. However, as Indefrey and Levelt (2004) pointed out, their temporal estimates contain some uncertainties, e.g. word form encoding duration ranges between 217 and 530 ms.

Dohmes et al. (2004) compared picture naming latencies in two sets of German items using the delayed variant of the picture-word interference paradigm (long-lag priming paradigm; Zwitzerlood et al., 2000; Feldman, 2000). In the first set, picture names (e.g. *Ente*, 'duck') were primed by either a semantically transparent or opaque compound (e.g. *Wildente*, 'wild duck', and *Zeitungssente*, lit. 'newspaper duck', 'false report', respectively). In the second set, prime words corresponded to semantically transparent compounds (e.g. *Buschrose*, 'bush rose') or contained the complete picture name (e.g. *Rose*, 'rose') only formally (e.g. *Neurose*, 'neurosis'). In each set, the priming effects were measured relative to an unrelated condition and picture naming latencies were facilitated by about 30–40 ms only for the morphologically primed conditions.

The present study extended the findings of Dohmes et al. (2004) to another language, Dutch. In addition, we also recorded ERPs in order to tap the time course of the associated brain activity during the overt naming of the pictures more directly. Two equivalent sets of Dutch stimuli were constructed (see Table 1 and Materials and methods section). For example, in Set 1, target picture names (e.g. *ekster*, 'magpie') were primed by either semantically transparent or opaque compounds (e.g. *eksternest*, 'magpie nest', and *eksteroog*, lit. 'magpie eye', 'corn/induration of the skin'). In Set 2, semantically transparent compounds served as prime words (e.g. *jaszak*, 'coat pocket'), or primes contained the complete picture name (e.g. *jas*, 'coat') without being a morpheme (e.g. *jasmijn*, 'jasmine'). A long-lag priming paradigm was employed using the same timing parameters as in Dohmes et al. (2004).

Faster RTs were expected in the morphologically related priming conditions (Dohmes et al., 2004). The effect should not be modulated by semantic transparency because it is supposed to originate at the word form level. That is, semantically transparent and opaque primes should result in similar morphological facilitation effects (Set 1). Semantically transparent, but not form-related primes should yield

**Table 1**  
Stimulus characteristics for both sets of stimuli

	Frequency	No. of syllables	No. of phonemes	Begin of overlap	Inter-trial lag
<i>Set 1</i>					
Targets	83	1.3	3.9	n/a	n/a
Primes					
Transparent	2.7	2.4	7.5	1.7	9.5
Opaque	2.7	2.6	8.0	1.6	9.8
Unrelated	2.8	1.9	5.0	n/a	9.7
<i>Set 2</i>					
Targets	67	1.0	3.2	n/a	n/a
Primes					
Transparent	2.9	2.5	7.2	1.6	9.5
Form-related	3.7	2.2	6.1	1.4	9.6
Unrelated	3.4	1.6	4.6	n/a	9.6

Frequency of occurrence – per one million; Begin of overlap in syllable position; average Inter-trial lag between primes and targets.

facilitation because transparent primes share a morphological representation with the picture while the form-related primes do not (Set 2). Similarly, a reduced N400 amplitude is expected for the morphologically related priming conditions (McKinnon et al., 2003). The N400 should be similarly reduced for transparent and opaque conditions but it should not differ between the form-related and unrelated conditions. The reduced N400 amplitude as a reflection of morphological priming is expected to begin around 330 ms after picture onset assuming an average naming latency of 600 ms (Indefrey and Levelt, 2004).

## Materials and methods

### Participants

Twenty-three (14 men) right-handed native speakers of Dutch participated for monetary compensation in the experiment. They were on average 24.7 years of age (range: 19–39). All participants had normal or corrected-to-normal visual and auditory acuity. Eight participants were excluded from the EEG analysis due to excessive movement artifacts. The remaining 15 participants (12 male) were on average 24.2 years old.

### Materials

Black and white line drawings of 72 common concrete objects were used as targets, thirty-six for each of the two sets of stimuli. Pictures of the first set were combined with two Dutch noun–noun compound words as primes. Both compounds contained the picture name as one constituent and one compound was semantically related to the picture name (transparent) whereas the other compound was not related to the picture name (opaque). For example, *eksternest* ('magpie nest') is semantically related to the picture name *ekster* but *eksteroog* ('corn') is not. Importantly, both compounds are morphologically related to the picture name. For the second set, the primes for each picture consisted of a semantically transparent Dutch noun–noun compound and a form-related word that contained the picture name fully but was not morphologically related to the picture name. For example, the picture of a coat (*jas* in Dutch) was paired with the compound *jaszak* ('coat pocket') and with the monomorphemic word *jasmijn* ('jasmine'). Notably, both words had the same phonological overlap with the picture name but only the transparent compounds were also morphologically related to the picture names. In order to assess the semantic transparency of the stimuli, a group of twelve students (4 male) who did not participate in the experiment rated the semantic relation of each compound to the corresponding picture name (e.g., *ekster*) on a 4-point scale (1–unrelated; 4–related). Opaque compounds (e.g., *eksteroog*) were rated less related (1.7) than

transparent compounds (e.g., *eksternest*) from Set 1 (3.7) or Set 2 (3.8;  $t(11)=19.4$ ;  $p<.001$  and  $t(11)=17.0$ ;  $p<.001$ , respectively). Pictures in each set were also paired with phonologically and semantically unrelated control words.

The three priming conditions in both sets were matched for frequency, number of syllables, and number of phonemes (Table 1). The same pictures were used as targets for naming within each set precluding any confound with other stimulus variables. Small differences among the prime characteristics that could not completely be avoided (e.g. number of phonemes of form-related and transparent compounds in Set 2) are highly unlikely to cause any effects because primes preceded targets by 7–10 trials. Previous research demonstrated that phonological and semantic priming does not survive such a distance (Zwitserlood et al., 2000; Feldman, 2000).

Morphological facilitation has been suggested to be independent of position of overlap (Zwitserlood et al., 2002) and, therefore, compound-picture pairs were selected such that picture names and primes overlapped either in the first or the second constituent. In the first set, the picture names overlapped with the primes' initial constituents in 33% of the transparent and 39% of the opaque compounds. In Set 2, the picture names overlapped with the primes in 53% of the transparent compounds with the initial constituent and in 69% of the form-related words with the initial syllable. However, the onset of overlap in form-related words was always aligned with a syllable boundary (Vroomen and De Gelder, 1997). Another 72 comparable pictures were paired with three semantically and phonologically unrelated words each and used as filler items to decrease the proportion of related stimuli.

### Design

The current experiment closely resembles a previous study in German that used a long-lag priming paradigm in which primes and targets are separated by 7–10 intervening trials (Dohmes et al., 2004). In two separate sets of stimuli, the relationship between prime words and target pictures was manipulated controlling for phonological overlap. Prime-target pairs were presented in three blocks, using a Latin-square design. Each picture occurred only once per block and each block contained 12 prime-target pairs of each condition per set. The 72 filler pictures were also presented once per block. In each block, the filler pictures were paired with a different word. Two trial sequences were used for each block, and participants saw the three blocks in one of six orders.

### Procedure

Participants were tested in two sessions separated by two weeks time. Behavioral data were acquired in the first, EEG data in the second session. Otherwise, both sessions were similar. Participants received a different randomization of stimuli in each session.

After having given written, informed consent, participants were seated in a dimly lit, soundproof, and electrically shielded room in front of a computer screen. After having received the instructions, participants saw each picture together with its name once on the computer screen for 3.5 sec, and they were required to name the pictures. This way, participants became familiar with the stimulus material. Next, participants received 20 word-picture pairs as practice trials to become familiarized with the experimental procedure. These trials were organized exactly as in the experimental blocks. Subsequently, all experimental stimuli were presented in three blocks with short breaks in between. The first session lasted about 60 min and the second about 1.5 hrs.

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 white on black background). Participants were instructed to read aloud

words and to name pictures as quickly and accurately as possible. Since stimulus names varied considerably in their number of syllables, time-out depended on the number of syllables. Time-out (showing a blank screen) was set to 1100 ms for monosyllabic and disyllabic, and 1400 ms for trisyllabic words. For all longer stimulus names, the time-out criterion was set to 1700 ms. Since all target picture names were monosyllabic and disyllabic, time-out was identical for all target trials. No feedback was provided during the experiment. The stimulus presentation and measurements were controlled by Presentation® software (version 9.13, [www.neuro-bs.com](http://www.neuro-bs.com)).

### EEG recordings

The EEG was recorded from 29 Ag/AgCl electrodes, placed according to the standards of the American Electroencephalographic Society (1991). Eye movements were monitored by recording the electrooculogram from the sub- and supra-orbital ridge of the left eye and the right and left outer canthus. The signals were band-pass filtered (0.05–30 Hz) and sampled with 250 Hz. The EEG signal was recorded using the left mastoid as the reference point and re-referenced off-line to the mean of both mastoids. Impedance for all electrodes was kept below 5 k $\Omega$ .

### Data analyses

Three word-picture pairs were discarded (*parel*, 'pearl' from Set 1, *klink*, 'door handle', and *lam*, 'lamb' from Set 2) because of error rates above 15%. For the EEG recording session, eight participants were excluded from further analyses due to excessive movement artifacts, i.e. when less than 10 trials passed the artifact rejection in any experimental condition. These artifacts were mostly due to overt speech and eye blinks. For reasons of comparability, behavioral and ERP results are reported for the same participants.

Mean picture naming latencies were submitted to by-participant ( $F_1$ ) and by-item ( $F_2$ ) repeated measurement ANOVAs with the factors Prime Type (3) and Block (3). Differences in mean RTs were evaluated in by-participant ( $t_1$ ) and by-item ( $t_2$ )  $t$ -tests. Original degrees of freedom and Greenhouse–Geisser corrected  $p$ -values are reported where applicable (RTs and ERPs). For the EEG analyses, automatic rejection was used to exclude all epochs containing (eye) movements during the time window 200 ms prior to and 700 ms following picture onset ( $\pm 75 \mu V$ ). Trials to which participants did not respond with the correct picture name (4.9%) were also excluded from the analyses.

As a consequence, 59.2% of the trials entered the averaging procedure. The majority of the rejected trials were excluded due to movement artifacts (e.g. premature verbal responses such as hesitations or stuttering, and eye blinks). However, the different experimental conditions were similarly affected: between 56.6% and 63.7% of the trials entered the analyses for each condition. Mean amplitude ERPs were calculated separately for each participant and each condition in relation to a 200 ms pre-stimulus baseline. The mean amplitudes were evaluated for the N400 between 350 and 650 ms post stimulus onset which is similar to the time window used in written and spoken word recognition (Hillyard and Kutas, 1983; Kutas and Federmeier, 2000). Six regions of interest (ROI) were constructed to test the scalp distribution of ERP effects; anterior-left (AL): F7, F3, FP1; anterior-right (AR): F8, F4, FP2; central-left (CL): FT7, FC3, T7, C3; central-right (CR): FC4, T8, C4; posterior-left (PL): TP7, CP3, P7, P3; and posterior-right (PR): TP8, CP4, P8, P4.



## Results

### Behavioral data

The mean RTs and error rates for all three conditions in both sets are shown in Table 2. The overall error rate was 7.1%. A two-way

**Table 2**

Stimulus examples, reaction times in ms (errors rates), RT difference (unrelated – prime) for all conditions in the behavioral session

Prime type	Example (prime)	Example (target)	$\Delta$ RT	RT
<i>Set 1</i>				
Transparent	eksternest (magpie nest)		36	644 (5.7)
Opaque	eksteroog (corn)		33	647 (6.6)
Unrelated	gnoom (hobgoblin)		n/a	680 (9.3)
<i>Set 2</i>				
Transparent	jaszak (coat pocket)		18	635 (8.0)
Form-related	jasmijn (jasmine)		3	650 (6.6)
Unrelated	otter (otter)		n/a	653 (6.3)

ANOVA for Set 1 yielded a main effect of Prime Type ( $F(2,28)=12.3$ ,  $p<.001$ ;  $F(2,68)=9.6$ ,  $p<.001$ ) and of Block ( $F(1,2,28)=9.9$ ,  $p<.01$ ;  $F(2,68)=8.7$ ,  $p<.001$ ). The interaction of Prime Type and Block was not significant (both  $F_s<1$ , ns). Subsequent  $t$ -tests revealed that picture naming was significantly facilitated when preceded by morphologically related, semantically transparent or opaque primes in comparison to unrelated primes (transparent:  $t(14)=4.1$ ,  $p<.01$ ;  $t(34)=3.6$ ,  $p<.01$ ; opaque:  $t(14)=4.4$ ,  $p<.01$ ;  $t(34)=3.5$ ,  $p<.01$ ). The transparent and the opaque conditions did not differ from one another (both  $t_s<1$ ; ns). In order to test for effects of repeated target presentation, mean RTs of the three blocks were compared by  $t$ -tests. Picture naming was faster during the second ( $t(14)=3.12$ ,  $p<.01$ ;  $t(34)=2.58$ ,  $p<.05$ ) and the third block ( $t(14)=4.25$ ,  $p<.01$ ;  $t(34)=3.78$ ,  $p<.01$ ) compared to the first (first block: 680 ms; second: 650 ms; third: 641 ms). However, RTs in block 2 and 3 did not differ in Set 1 ( $t(14)=1.1$ , ns;  $t(34)=1.52$ , ns).

For Set 2, the same two-way ANOVAs were performed, and a marginally significant main effect of Prime Type was obtained ( $F(1,2,28)=3.33$ ,  $p=.06$ ;  $F(2,66)=3.0$ ,  $p=.05$ ). The main effect of Block

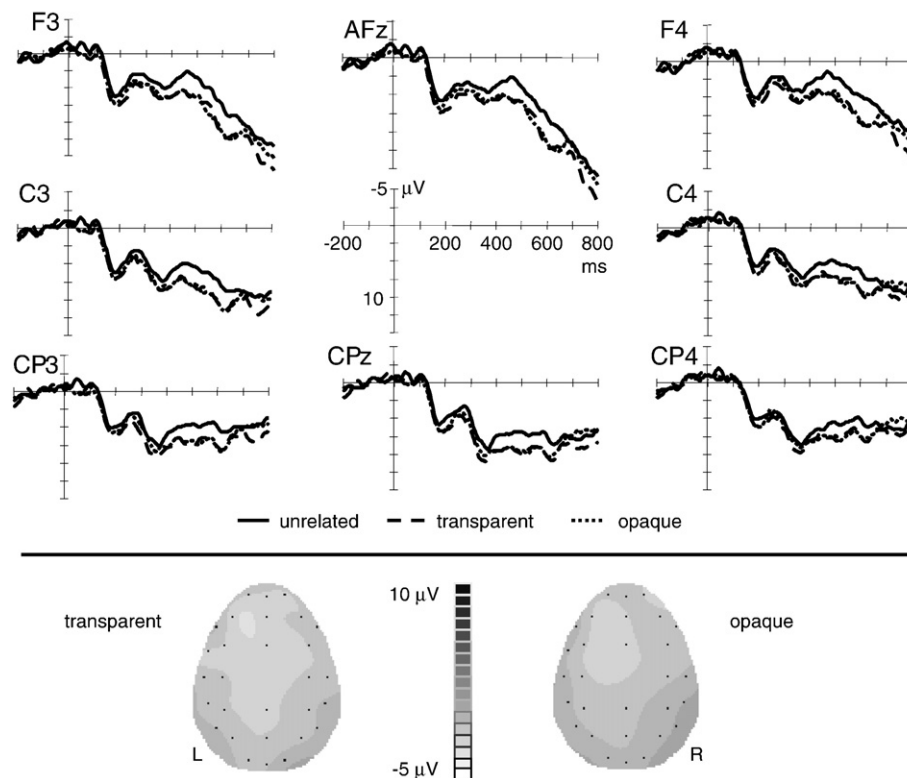
was significant ( $F(1,2,28)=23.3$ ,  $p<.001$ ;  $F(2,66)=24.9$ ,  $p<.001$ ) but the interaction of Prime Type and Block was not (both  $F_s<1$ , ns). Subsequent  $t$ -tests showed that picture naming was facilitated by semantically transparent primes (marginally significant by-items:  $t(14)=3.0$ ,  $p=.01$ ;  $t(33)=1.9$ ,  $p=.06$ ). In contrast, form-related primes did not facilitate picture naming significantly (both  $t_s<1$ , ns). The transparent and form-related conditions differed in the by-items but not in the by-participants analysis ( $t(14)=1.6$ , ns;  $t(33)=2.9$ ,  $p<.01$ ).  $t$ -tests performed to follow up the main effect of Block showed that RTs were significantly reduced in the second compared to the first block (first block: 673 ms; second block: 641 ms;  $t(14)=3.89$ ,  $p<.01$ ;  $t(33)=4.83$ ,  $p<.001$ ) and in the third compared to the second block (third block: 625 ms;  $t(14)=2.91$ ,  $p<.05$ ;  $t(33)=2.25$ ,  $p<.05$ ). The difference between the third and the first block was also significant ( $t(14)=6.43$ ,  $p<.001$ ;  $t(33)=5.9$ ,  $p<.001$ ).

#### ERP data

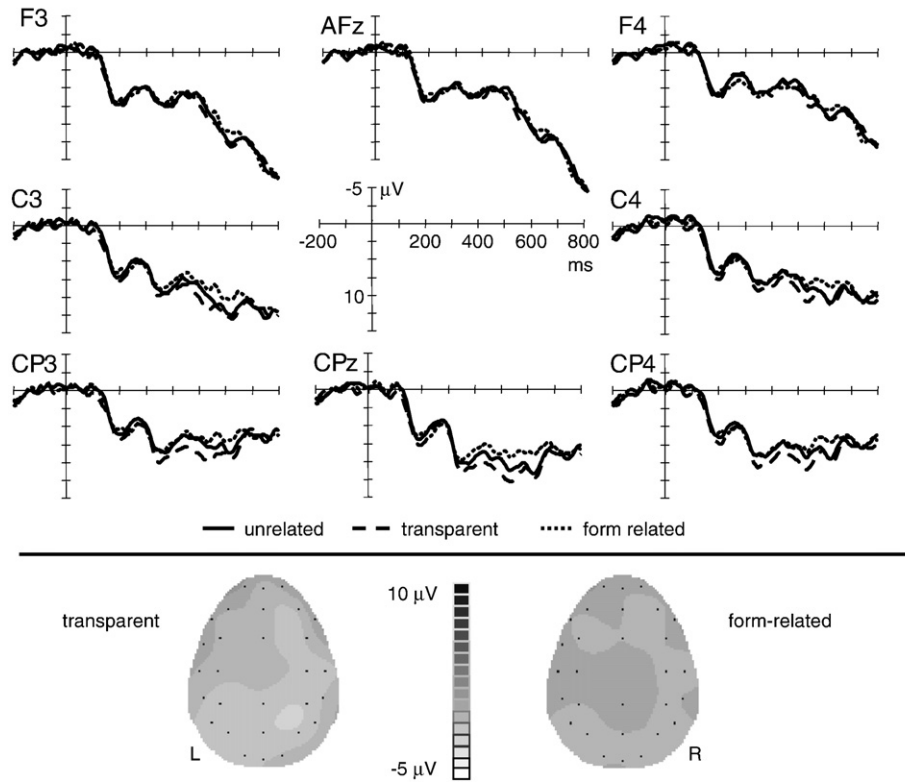
The mean amplitude values were compared for both sets in a three-way ANOVA with the factors Prime Type (3), Anterior–Posterior (AP) Location (3), and Hemisphere (2) between 350 and 650 ms post target onset. The overall error rate in the second session was 4.9%.

For Set 1 (Fig. 1), the overall ANOVA yielded a main effect of Prime Type ( $F(2,28)=8.7$ ,  $p<.01$ ) which did not interact with either spatial factor (all  $F_s<2.1$ , ns). Subsequent  $t$ -tests were performed across all ROIs. The mean ERP amplitude was reduced (i.e. less negative) for picture naming primed by transparent ( $t(14)=4.4$ ,  $p<.01$ ) and opaque compounds ( $t(14)=3.6$ ,  $p<.01$ ), and the ERP amplitude of the transparent and opaque conditions did not differ from one another ( $t(14)<1$ , ns).

For Set 2 (Fig. 2), the overall ANOVA yielded an interaction of Prime Type and AP ( $F(4,56)=15.3$ ,  $p<.001$ ). Neither the main effect of Prime



**Fig. 1.** Grand average ERPs, superimposed for the two morphologically related (dashed line: semantically transparent; dotted line: semantically opaque) and the unrelated conditions (solid line) in Set 1 (upper panel). The ERPs are time-locked to the onset of picture presentation, and negativity is plotted upwards in this and all subsequent figures. Isovoltage maps of the unrelated minus related conditions in the N400 time window (lower panel).



**Fig. 2.** Grand average ERPs, superimposed for the morphologically related (dashed line: semantically transparent), the form overlap (dotted line), and the unrelated condition (solid line) in Set 2 (upper panel). The ERPs are time-locked to the onset of picture presentation. Isovoltage maps of the unrelated minus related conditions in the N400 time window (lower panel).

Type nor any other interaction was significant (all  $F_s < 1.4$ , ns). To follow up the interaction of Prime Type and AP, one-way ANOVAs with the factor Prime Type (3) were performed separately for the anterior, the central, and the posterior ROI. The posterior ROI showed a significant effect of Prime Type ( $F(2,28)=7.7$ ,  $p < .01$ ) but not the anterior or central ROIs (all  $F_s < 1.8$ , ns). Subsequent  $t$ -tests in the posterior ROI revealed a reduced ERP amplitude for the transparent compared to the unrelated condition ( $t(14)=2.9$ ,  $p < .05$ ). The form-related condition did not differ from the unrelated condition ( $t(14) < 1$ , ns). Consistently, the transparent condition elicited also a reduced ERP amplitude in comparison to the form-related condition ( $t(14)=3.3$ ,  $p < .01$ ).

In order to check whether the priming effects are already significant before 350 ms, supplementary ANOVAs were performed in subsequent 50 ms time windows between 0 and 350 ms. The analyses with the factors Prime Type (3), AP (3), and Hemisphere (2) did not yield any significant main effect of Prime Type or any interaction involving Prime Type.

## Discussion

This study investigated morphological priming in overt Dutch speech production. Picture naming latencies were shorter when preceded (7–10 trials earlier) by a morphologically related compound word. The amount of facilitation did not differ between semantically transparent and opaque compounds. Furthermore, priming by mere form overlap did not facilitate picture naming significantly. The ERP results confirmed this pattern. ERP amplitudes were consistently reduced at posterior scalp regions when naming a picture that was primed by a morphologically related compound (transparent or opaque) between 350 and 650 ms after picture onset but not for priming by mere form-related words. The reduced negativity is interpreted as an N400 effect as the N400 is sensitive to morphological processing (McKinnon et al., 2003). The main results confirm our

predictions, previous findings from German (Dohmes et al., 2004; Exp. 2), and extend them to Dutch. Also, the N400 effect shows that ERPs can be recorded reliably during overt picture naming.

Dohmes et al. (2004) proposed that the effects obtained in their German priming study were due to genuine morphological processes. Along the same lines, we argue that the present effects cannot be explained by the semantic or phonological relationship between primes and targets because semantic and phonological effects do not survive the distance between prime and target in a long-lag priming paradigm (Feldman, 2000; Zwitserlood et al., 2000). Thus, the effects are suggested to be due to the morphological relation between prime and target.

Others have denied a psycholinguistic basis for morphological representations. Morphological effects are supposed to emerge as the result of semantic and word form processing as well as their interaction (Joanisse and Seidenberg, 1999, 2005; Plaut and Gonnerman, 2000). However, if the present facilitation effects were influenced by semantic processes, semantic transparency should have resulted in a difference between transparent and opaque conditions (Set 1) in the behavioral and the ERP data. Specifically, one would expect increased RTs for the production of picture names (e.g., *ekster*, 'magpie') primed by transparent (e.g., *eksternest*, 'magpie nest') relative to opaque compounds (e.g., *eksteroog*, 'corn') due to lexical competition (Glaser and Glaser, 1989; Levelt et al., 1999). Importantly, the absence of a difference between the transparent and opaque conditions cannot be explained by a putative phonological effect that annihilated the semantic one because the transparent and opaque conditions did not differ with regard to their phonological overlap with the picture names.

Similarly, if the observed effects were influenced by phonological processes, form overlap should have resulted in a significant facilitation in Set 2. However, facilitation for naming a target picture (e.g., *jas*, 'coat') was only found for morphologically related primes (e.g., *jaszak*, 'coat pocket') although the effect was weaker than in Set

1. In other words, the absence of an effect for mere form-related primes (e.g., *jasmijn*, ‘jasmine’) suggests that the effect for morphologically related primes is not due to phonological overlap because the phonological overlap was the same in both conditions. Moreover, together with the absence of a semantic influence as suggested by the data from Set 1, the facilitation for morphologically related primes in Set 2 cannot be accounted for by the semantic relation with the target picture name. Rather, it is suggested that the effects are due to the morphological relation between primes and targets, and that these relations are explicitly represented in the mental lexicon and its neurocognitive substrate (Badecker, 2001; Zwitserlood et al., 2000). Thus, the present results are consistent with the conception of morphology as being independent of semantics (Aronoff, 1994; but see Marslen-Wilson et al., 1994).

The repeated picture presentation across the three blocks led to reduced picture naming latencies in both stimulus sets. This effect is consistent and comparable to previous findings (Zwitserlood et al., 2000, 2002). Importantly, the block effect did not interact with the manipulation of primary interest, i.e. Prime Type. Therefore, it is suggested that the general facilitation across blocks is independent of linguistic processes. This repetition effect may reflect the more efficient visual processing or recognition of the pictures.

The present findings support decompositional models of (compound) word production. The effect of a morphological relation between compound constituents and picture names suggests that the morphemes are available to the parser and may be planning units in language production (Roelofs, 1996; Roelofs and Baayen, 2002). Morphologically complex words, at least compounds, seem not to be stored and prepared as whole-word forms. That is, a full-listing account (e.g., Butterworth, 1983) is incompatible whereas full-parsing and dual-route models are compatible with the present data (Badecker, 2001; Bien et al., 2005; Blanken, 2000; Levelt et al., 1999; Stemberger and MacWhinney, 1986; Taft, 2004).

Previous findings suggest that morphological priming effects in a long-lag priming paradigm are independent of the position of overlap between picture names and compound constituents (Zwitserlood et al., 2002). Accordingly, our material sets were not required to match exactly regarding the amount of this overlap. The overlap between picture names and initial constituents was reduced in Set 1 (33% and 39% for transparent and opaque compounds, respectively) compared with Set 2 (53% for transparent compounds). Unlike Dohmes et al. (2004), we found reduced priming effects (in RTs and ERPs) for transparent compounds in Set 2 compared to Set 1 which might be due to the different amount of overlap. One would expect larger priming effects for increased overlap in initial constituent positions, and the strict serial planning assumption might also lead to the expectation of larger priming effects for initial constituents (Roelofs, 1996, Roelofs and Baayen, 2002; but see below). However, we obtained larger effects in Set 1 where the overlap with initial constituents was reduced.

An alternative explanation might relate to the fact that modifier and head constituents, i.e. first and second constituents in our experiment, are not processed alike. For example, in a series of language production experiments Bien et al. (2005) investigated how different variables of the modifier and the head constituents affect the naming latencies of Dutch compounds. Interestingly, all relevant variables of the modifier had facilitative effects whereas facilitative and inhibitory effects were found for the head constituents. However, an additional inhibitory effect of head constituents in our experiment (during prime word pronunciation) cannot explain the reduced priming effects in Set 2 either, because picture names overlapped more often with the second constituents in Set 1 (67% and 61% for transparent and opaque compounds, respectively) than in Set 2 (47% for transparent compounds). Hence, reduced priming effects should be observed in the first and not in the second set of stimuli. Note that Bien et al. (2005) used

an experimental paradigm that is difficult to compare directly to the present paradigm.

On the basis of our findings, we cannot completely exclude an effect of position of constituent overlap. Based on the current data, a potential position of overlap effect cannot be disentangled from effects due to different materials in the two sets of stimuli. When position of overlap was balanced (50% initial vs. 50% second; Zwitserlood et al., 2002), an equal amount of priming was obtained for each constituent. However, the equal balancing may have led to the similar amount of priming. Further research is needed to clarify this issue, possibly by manipulating the amount of overlap within an experiment. Finally, subtle differences between the stimuli in both sets, ranging from physical–visual characteristics of the pictures to their conceptual properties, might have interfered with the processes of interest and have reduced the amount of facilitation. In contrast to the study of Dohmes et al. (2004), material effects are suggested to be the primary cause of the different priming effects in the present study.

The question of whether the preparation of morphemes is strictly serial (Roelofs, 1996; Bien et al., 2005) may be related to the constituent overlap effect. However, our data do not speak to the question of serial preparation. Firstly, we used a distinct paradigm which is not completely comparable (see also Zwitserlood et al., 2002). Secondly, both constituents of the prime words were planned and articulated before the target picture was named in our study. Exactly this planning of the constituents is supposed to result in the morphological priming effect. A potential preparation effect, namely that first constituents are planned before second constituents (Roelofs, 1996) is unlikely to affect picture naming 7–10 trials later given that phonological and semantic effects do not survive this distance.

The time course of the ERP priming effects is in good agreement with the temporal estimate for morphological encoding but not with other processing stages such as conceptual preparation or lemma retrieval (Indefrey and Levelt, 2004). According to Indefrey and Levelt (2004), semantic/conceptual processing is estimated to begin around 175 ms after a picture is presented (for naming). Around 250 ms after picture onset, the lemma is selected and morphological encoding, the first process in word form encoding begins about 330 ms after picture presentation. The onset of the N400 effect in the present study is similar to the estimated onset of morphological encoding (Figs. 1 and 2). The estimates by Indefrey and Levelt (2004) are relative to a response latency of 600 ms. If the onset of morphological encoding is scaled to a response latency of 650 ms, i.e. approximately our observed mean RTs, an estimate of 358 ms is obtained for the begin of morphological encoding. This estimate is very close to the onset of the N400 effects in both stimulus sets. The N400 effects, therefore, support the hypothesis that morphological priming originates at a relatively late stage during picture naming, namely morphological encoding. That is, morphological priming effects seem to originate at the word form level.

While the time course of the N400 effects is in accordance with theoretical suggestions, the scalp distribution of the N400 effect for the transparent priming conditions differed between the two stimulus sets. In both sets, the N400 effect was reliable at posterior sites, and it was also reliable at central and anterior sites in Set 1. Here, it is suggested that material effects may be related to the different scalp distributions. Material effects may have interfered with the morphological priming and may have led to reduced activity in the underlying neural generators of the N400. A smaller facilitation effect in Set 2, as suggested by the smaller behavioral priming effect, is compatible with such a reduced generator activity (Urbach and Kutas, 2002). Hence, it is conceivable that the effect was detected only at a more focal subset of scalp electrodes in Set 2 but nevertheless reflected the same underlying neural generator configuration. At any rate, ERPs are known to have a limited spatial resolution. Further research may combine profitably the current experimental design with the method



of functional magnetic resonance imaging in order to determine more directly the neural substrate of morphological priming in overt language production.

To our knowledge, N400 effects have not been reported for morphological processing in overt picture naming studies but the N400 has been suggested to be sensitive to morphological processing in visual word recognition/comprehension (McKinnon et al., 2003). It is noteworthy that the amplitude of the N400 is reduced in visual word processing as is also the case for the present N400 effect during picture naming. Similarly, ERPs have been used to investigate priming effects of covert picture naming (preparation) on subsequent auditory word comprehension (Jescheniak et al., 2002). Semantically and phonologically related picture names resulted in reduced ERP amplitudes (less negative) compared to unrelated picture-word pairs. These results demonstrate that the automatic activation of semantic and phonological representations during the preparation of a picture name can be assessed indirectly by the influence of the activated information on subsequent word comprehension. While this method complements approaches that require meta-linguistic decisions (e.g. animacy or syntactic gender, e.g. Schmitt et al., 2000; Van Turenout et al., 1997), the current experiment shows that processes in overt language production (e.g. morphological priming) can be investigated with ERPs reliably and more directly.

A major issue in overt language production with ERPs is the exclusion of trials and participants due to movement artifacts which potentially reduces the signal-to-noise ratio. The reduced number of trials may be less of a problem for rather strong ERP components such as the error-related negativity (Falkenstein et al., 1990; Ganushchak and Schiller, 2006, 2008). The present ERP experiment demonstrates that also later components can be detected reliably in overt picture naming (see also Christoffels et al., 2007). One way to address this issue may be the inclusion of more experimental trials if possible. The observed drop-out rate also calls for artifact correction tools that go beyond compensating for ocular activity (e.g. Hesse and James, 2006; Ting et al., 2006).

To conclude, in a long-lag priming paradigm, picture naming was facilitated by the previous production of morphologically related, complex words. This morphological priming was associated with an N400 effect in the ERP. The behavioral and ERP priming effects were not modulated substantially by semantic or phonological information. The facilitation appears to originate during a relatively late processing stage in picture naming that corresponds to the temporal estimate of morphological encoding. Thus, morphological priming is suggested to facilitate language production at the word form level (i.e. during morphological encoding) and to be independent of semantic and phonological processes.

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