CHAPTER 28

MORPHOLOGICAL THEORY AND NEUROLINGUISTICS

NIELS O. SCHILLER AND
RINUS G. VERDONSCHOT

28.1 What is neurolinguistics?

Neurolinguistics is a research area bearing upon the relationship between the brain and language functions (Ingram 2007). In fact, the boundaries between psycho- and neurolinguistics are not sharp (Schiller 2009)—both terms are used to describe scientific research on the relationship between linguistics, cognitive psychology, and the brain. Although all language functions ultimately reside in the brain, neurolinguistics rather than psycholinguistics emphasizes the neuroscientific aspect. For an overview of morphological theory and psycholinguistics we refer the reader to the chapter by Gagné and Spalding (Chapter 27 this volume).

On the one hand, the term neurolinguistics is used to refer to research on language processing involving neuropsychological patients suffering from some sort of language disorder or impairment. Damage to many individual brain areas can result in language impairment. Spoken and written language (or gestures) can be independently affected, and also production and comprehension can be dissociated. Language impairment may result in different sorts of aphasias (Goodglass 1993), the best known being Broca's and Wernicke's aphasia, however, it has been suggested that these are rather coarse labels (e.g. Schwartz 1984) and that “we must develop a new, theoretically motivated typology of aphasia based on psycholinguistic principles” (Caramazza 1984: 9).

On the other hand, the term neurolinguistics—rather than psycholinguistics—is used to indicate research on language processing that employs some sort of *brain imaging* or *neural manipulation technique*, ranging from electrophysiological (e.g. event-related brain potentials or ERPs) to hemodynamic (e.g. functional magnetic resonance imaging or fMRI) methods. In fact, neuroimaging research methodology is rapidly developing, and methods such as positron emission tomography (PET), magneto-encephalography (MEG), near-infrared spectroscopy (NIRS), transcranial magnetic stimulation (TMS) or transcranial direct current stimulation (tDCS) are widespread. Neuroimaging research may be carried out with patients, but is generally conducted with healthy participants. In fact, whenever the neurological substrate and its relation to language processing is at issue, as is the case with neuropsychological patients suffering from structural brain damage or with imaging methods measuring the function (or activity) of brain tissue, we deal with neurolinguistics.

These two research traditions developed relatively independently of each other, with researchers publishing in different journals and presenting their work at different conferences. We will try to report work and relevant findings from both areas in this chapter, that is, from healthy speakers as well as language-impaired individuals. Some models of language processing, for instance on speech production, derive from the neuropsychological tradition (such as Caramazza's *Independent Network* model; Caramazza 1997) whereas others derive from the tradition of neuroimaging (such as Indefrey and Levelt's model of language production; Indefrey and Levelt, 2004; Indefrey, 2011; strongly influenced by Levelt, Roelofs, and Meyer, 1999). Due to these differences in source data, models differ as well. In principle, however, all types of model should be able to account for different types of data.

Regarding electrophysiological and hemodynamic data, we will mainly refer to ERP and fMRI work here. Electroencephalography (EEG), and derived from it ERPs, can measure brain activity—electrical currents produced by synaptic activity—with millisecond (ms) temporal resolution, while its spatial resolution is less fine-grained due to the *inverse problem* (Grech et al., 2008), but can be approximated with the help of electrical dipole modeling. ERPs consist of a number of components, negative (such as the N400, ELAN, and LAN) or positive (such as the P600) in polarity, which are characteristic for certain linguistic processing responses. For instance, the N400, first described by Kutas and Hillyard (1980, 1984), is a voltage peak of negative polarity in the brain that reaches its amplitude maximum around 400 ms after the onset of the stimulus word. Every word yields an N400 component, however, when comparing a contextually appropriate with a non-appropriate word, the difference in N400 amplitude is referred to as the N400 effect (see also Figure 28.1). While it was initially believed that the N400 is especially sensitive to semantic features of words, it is now thought that this component reflects the ease of integrating words into context. The P600 effect, initially also known as the syntactic positive shift (SPS; Hagoort, Brown, and Groothusen, 1993), is a relatively late, syntax-related ERP component with positive polarity. It is observed as a consequence of violations of syntactic structures or preferences (so-called *garden-path* structures) and difficulty of syntactic integration (e.g. Kaan et al. 2000). The Early Left Anterior Negativity (ELAN) is another component with negative polarity, usually peaking between 100–200 ms, which is evoked by syntactic phrase structure violations (Neville et al. 1991; Friederici, Pfeifer, and Hahne, 1993) and reflects highly automatic processes of initial structure processing. More interesting in light of the topic of the current chapter is the LAN (Left Anterior Negativity) component, which occurs somewhat later (i.e. between 300 and 500 ms) and reflects morpho-syntactic aspects of sentence processing, such as subject–verb agreement violations (Gunter, Stowe, and Mulder, 1997; Penke et al. 1997).

28.2 NEUROLINGUISTIC APPROACHES TO MORPHOLOGICAL PROCESSING

28.2.1 Morphological processing models

Morphologically complex (as opposed to simplex) words are word forms that consist of more than one meaning-bearing element, that is, more than one morpheme. Morphologically complex word forms can be derived or inflected words, or they can be compounds. Derivational morphemes are affixes that are added to a simplex form to change its meaning (e.g. '*un*' + '*happy*' → '*unhappy*') or grammatical function by changing its syntactic word class (e.g. '*happy*' + '*ness*' → '*happiness*'). Inflectional morphemes, in contrast, are affixes that do not change the meaning or syntactic word class of a word, but carry grammatical meaning and have the purpose to complete grammatical agreement (e.g. '*I buy a book*' vs. '*She buys* [3rd person singular -*s*] *two books* [plural -*s*]'). A compound consists of more than one simplex morpheme (or stem), either of the same (e.g. '*paperback*') or different syntactic word classes (e.g. '*hardcover*'). Important processing questions concern the way in which morphologically complex word forms such as '*books*' ['*book*' + plural '*s*' morpheme] or '*worked*' ['*work*' + past tense '*ed*' morpheme] are processed by our neurolinguistic system. How are complex words represented in the mental lexicon and how are they accessed, that is, as full forms (e.g. *books*, *worked*) or via their constituent morphemes (e.g. *book* + *s*, *work* + *ed*)? Psycholinguists came up with different answers to these questions.

Most work has been carried out in the area of language comprehension. Butterworth (1983, 1989), for instance, proposed that complex words are listed as entire word forms (so-called *full-listing models*). For instance, morphologically related word forms such as *work*, *works*, *worked*, *working*, *workable*, *worker*, *workaholic*, *homework*, etc. are all fully listed and represented by separate entries in the lexicon. Morphology does not play a significant role in those models. However, the plausibility of full-listing models becomes questionable in the light of agglutinative languages, in which affixes attach to the base morpheme to express syntactic or semantic properties (Waksler 2000). In contrast, other scholars have suggested separate access of individual morphemes, for instance, in compounds (so-called *full-parsing* or *decompositional models*; e.g., Rastle and Davis 2008; Taft and Forster 1975, 1976; Taft 2004). That means that, for example, derivations such as *workable* may not be stored as holistic units. Instead, the individual morphemes *work* and *able* would be accessible to the processing system. Complex words would have to be decomposed into their constituents before the word stem could be accessed. This view is supported, for instance, by data from experiments manipulating frequency, that is, higher constituent frequency is associated with faster naming (Bien, Levelt, and Baayen, 2005; see Janssen, Bi, and Caramazza, 2008 for contrasting results). Finally, *dual-access models* have been suggested, starting with Frauenfelder and Schreuder (1992), which postulate two distinct access routes to complex words, that is, a direct route which is followed, for instance, to access irregular past tense forms and an indirect route to access regular complex words and decompose them into their underlying constituent morphemes (Pinker 1999; Isel, Gunter, and Friederici 2003).

The production of morphologically complex words has been less investigated. In the language production model by Levelt and colleagues (Levelt, Roelofs, and Meyer 1999; but see also Caramazza 1997; Dell 1986), the encoding of meaning (conceptual-semantic processing) precedes the encoding of form (phonological-phonetic processing). However, models diverge when it comes to the exact time-course of information flow from conceptual preparation to phonological-phonetic encoding and finally the articulatory motor movements necessary to produce speech. Levelt's model assumes that sematic concepts activate a number of lexical nodes, however, subsequently only one such node can be selected and further encoded at the phonological level. Whether morphologically complex words are stored and accessed as wholes, is not completely clear. In fact, a decomposed representation of, for instance, compound words or inflected words, would avoid a duplication of the representation of the constituents. In fact, there is some evidence for this position from production naming studies manipulating lexical frequency; naming latencies are predicted by the frequencies of the constituents but not the frequency of the compound (Bien, Levelt, and Baayen 2005).

Additional evidence for a dual-route model comes from studies on the neurobiology of morphological processing. For instance, Leminen et al. (2011) found in a combined EEG/MEG study that the processing of inflected words activated more strongly left superior/middle temporal cortices, whereas this left-hemispheric activity was not found for derived words. Derived words, in contrast, activated right superior temporal areas. Interestingly, a recent morphological priming ERP study on Spanish inflection and derivation reported electrophysiological differences for these two word types as well (Alvarez et al. 2011). Moreover, Bozic and Marslen-Wilson (2010) argue that morphologically complex words created by rule-based combinations of morphemes such as inflected words (e.g. *work-ed*, *jump-s*) engage a left-lateralized fronto-temporal subsystem, specialized for grammatical computations. In contrast, lexicalized combinations such as found in derived words (e.g. *brave-ly*, *warm-th*) engage a bilateral subsystem to access whole-word, stem-based lexical items. That is, the distinction between inflection and derivation may have a neurobiological processing correlate. As we will see, the processing of compounds may activate still other underlying neural areas.

28.2.2 Comprehension of morphology

To allow for successful language production and communication, processing morphological structure plays an important role in day-to-day language use. For instance, verb inflections are interesting as they can be regular (*walk* > *walked*) or irregular (*swear* > *swore*). Regular and irregular verb inflections have been extensively studied since the late 1970s until the present day with a particular interest in whether both are processed by similar or distinct systems in the brain. In the following, we present a selection of electrophysiological (EEG/ERP) as well as neuropsychological studies (with patients) which have investigated the comprehension processes in the brain related to morphology.

28.2.2.1 *Electrophysiological studies on morphological violations*

One way to investigate how morphological (de)composition in the brain takes place is to observe how the brain reacts when faced with uncommon situations. One often used method to investigate this is the morphological violation paradigm (e.g. Penke et al. 1997; Rodriguez-Fornells et al. 2001). In this paradigm, correct and incorrect forms of particular morphological combinations (e.g. verbs plus their suffixes) are embedded into lists, sentences, or short stories, and by observing specific event-related brain potentials one can determine whether or not the brain considers particular combinations as violating morphological rules.

To distinguish between different models of morphological processing, Penke et al. (1997) employed the morphological violation paradigm to investigate how the brain responds to correct and incorrect forms. This study used both regular (ending in -*t*; such as *getanzt* 'danced') and irregular German participles (ending in -*en*; such as *geladen* 'loaded'). Participants were presented with correct and incorrect participle forms while recording their brain activity using electroencephalography (EEG). Penke et al. conjectured that if all morphological forms are simply stored, no differences should be found between violations for regular and irregular forms, that is, they should show similar event-related potentials (ERPs). Alternatively, if all forms are decomposed into their stem and affix regardless of their regularity, once again similar brain responses should be found for both regular and irregular violations. However, Penke et al.'s results showed that only *incorrect irregular* participles (e.g. **aufgeladet*) produced a so-called LAN effect (a left fronto-temporal negativity) reflecting processes involved in morphological structure building and, remarkably, there was no difference observed for incorrect regular participles. Penke et al. therefore concluded that regularly inflected words are processed differently from irregularly inflected words. In other words, their results favor a dual-mechanism model in which regularly inflected words are decomposed into their stems and affixes and irregularly inflected words are processed by accessing full-form entries stored in the lexicon.

Rodriguez-Fornells et al. (2001) assessed the generalizability of Penke et al.'s (1997) ERP results to Catalan (a Romance language). The advantage of studying Catalan is that verb stems in this language are further decomposable into a root and a thematic vowel (indicating conjugation class), simultaneously allowing for the study of stem formation and affixation during morphological encoding. This extends the scope from concatenation to stem alteration, thereby permitting generalizations across the functional role that particular ERP components (e.g. LAN, P600, N400) play during morphological encoding. By embedding correct and incorrect forms of stems and participles in short stories, Rodriguez-Fornells et al. (2001) found left-lateralized negativities (i.e. LAN effects) for stem violations but not for incorrect participles. Conversely, a P600 effect was found for both violations (not obtained in German by Penke et al., 1997). They speculated that the absence of a LAN effect for incorrect participles might have its origin in the fact that the incorrect irregular participles used in the Catalan study had an incorrect stem and were therefore less obviously related to their accurate forms. Consequently, violations were less obvious in Catalan than in the German stimuli used in earlier studies. The occurrence of a P600, however, was not surprising as the P600 is usually involved in the re-analysis of a whole sentence (as the comprehension task in the study required). According to Rodriguez-Fornells et al., the absence of the P600 in Penke et al. (1997) may have been due to the fact that either their analysis time window was too short (as the P600 is a late component), word-lists were used (avoiding re-analysis which typically evokes a P600), and/or words were used at the end of the sentence (which typically elicit a positivity which could have masked the effect). Importantly, however, Rodriguez-Fornells et al. (2001) concluded that the LAN indeed selectively reflects processes involved in morpho-syntactic structure building and, corroborating Penke et al. (1997), they established that a dual-mechanism involving lexical memory for irregular items and rule-based processes for regular items seems to apply to both inflectional and stem-forming processes.

Contrastingly, Smolka et al. (2013), using ERPs, reached a different conclusion. As stated earlier, previous research suggested that irregular and regular (past) tense for verbs supported the existence of two distinct systems, that is, a system which only stored the base (for regular inflected verbs) and another system storing the whole word form (for irregular inflected verbs). Smolka et al. (2013), however, proposed that in previous violation paradigm studies, as well as other (repetition priming) studies (e.g. Rodriguez-Fornells, Münte, and Clahsen, 2002), there were several inconsistencies between the paradigms (i.e. patterns of dissimilar effects in violation paradigms but comparable effects in priming paradigms; see Smolka et al. 2013: 1287, Table 1). Additionally, Smolka et al. (2013) pointed out the existence of several studies demonstrating "graded" brain responses depending on verb regularity (e.g. Justus et al. 2008) which would suggest a single-system account. To discern between a categorical (dual-system) or a more continuous single system involved in word processing, they reported data from a visual priming experiment using German in which participle formation was examined. Five conditions were constructed, (1) identity (*lerne/lerne* '(I) learn'); (2) participle (*lerne/gelernt* '(I) learn/learnt'); (3) semantic associate with the same inflection (*lerne/büffle* '(I) learn/(I) cram'); (4) semantic associate in participle form (*lerne/gebüffelt* '(I) learn/crammed'); (5) and unrelated (*lerne/trockne* '(I) learn/(I) dry'). The crucial manipulation concerned the participle condition for different targets. So, for a target such as *backe* ('(I) bake') the participle is *gebacken* (regular stem but an irregular suffix, i.e. semi-irregular), for a target such as *trinke* ('(I) drink') the participle is *getrunken* (both irregular stem and suffix, i.e. fully irregular). As a dichotomous system predicts similar effects regardless of the amount of irregularity, graded effects (manifested in, for instance, amplitude/topography or latency of the ERP) would be difficult to explain. Smolka et al. (2013) indeed showed that behaviorally as well as in ERP data, graded patterns were dependent on verb regularity. That is, regular verbs produced the largest and most widely distributed effects, irregular verbs produced small and the least widely distributed effects, and semi-irregular verbs produced an effect and distribution in between regular and irregular verbs. These results argue against a dichotomous (regular/irregular) explanation and favor a continuous system for processing verbs in German.

28.2.2.2 *Neuropsychological studies on morphological violations*

Another way to assess how morphological processing in the brain takes place is by studying patients who have neurological impairments such as dyslexia or aphasia. One particular avenue of research concentrates on a condition known as *deep dyslexia* in which morphological errors are quite prominent (Coltheart, Patterson, and Marshall, 1980). Deep dyslexia is an *acquired* disorder, which means that the patient suffering from the disorder was able to read normally before the brain trauma occurred. This disorder is usually characterized by having multiple reading difficulties. People having deep dyslexia usually have great difficulty processing non-words (e.g. they are unable to read **toble*), function words (reading *in* instead of *at*), and would make frequent visual (reading *whisk* as *wheel*) and semantic errors (reading *cousin* instead of *father*). Importantly, they also show poor performance in reading morphologically complex words (e.g. reading *worker* instead of *working*). Importantly, the latter indicates that these patients still seem able to decompose words into their constituent morphemes (i.e. stem + affix) but have difficulties affixing particular (bound) morphemes (such as -*y*, -*ness*, -*er*, -*ity*, and -*ing*). Originally, affixation errors such as these were indeed seen as representing a separate component within the reading process which, when damaged, would yield morphological errors (Morton and Patterson 1980; Job and Sartori 1984). However, subsequent research speculated whether or not these errors were in fact semantic or visual in nature (Badecker and Caramazza 1987; Funnell 1987). Badecker and Caramazza (1987), for instance, argued that many errors, which were defined as morphological, could also be explained by examining the concreteness of words (concrete vs. abstract words). They concluded that it was difficult to settle the issue regarding whether there is a separate morphological level that was damaged or whether deficiencies were due to visual/semantic complications. Similarly, Funnell (1987) investigated this issue by examining the imageability and frequency of both the intended words and the incorrectly read words. If affixation errors were genuinely morphological in nature, they should only be observed with truly affixed (e.g. *worker*) but not with pseudo-affixed words (e.g. *corner*) or embedded words (e.g. *fall* in *fallacy*). However, Funnell (1987) found, for instance, that the word *mastery* would be read as *master* and the word *salty* would be read as *salt*. Although such errors would have previously been classified as morphemic errors, Funnell (1987) stated that what the patient read, in fact also tended to be the most imageable words (i.e. both *master* and *salt* have a higher imageability than *mastery* and *salty*). Importantly, these errors also appeared in pseudo-suffixed words (e.g. *treaty* would be read as *treat*) and for embedded words (e.g. *fallacy* would be read as *fall*) for which patient (JG) would usually produce the (apparent) stem of a word. The difference in error rates between pseudo-affixed words, embedded words, and truly affixed words was—although numerically larger for truly affixed words than for the other categories—not statistically different. It was therefore concluded that morphological errors produced in reading aloud are likely caused by similar underlying reasons, such as imageability and word frequency, that constrain reading performance when processing non-affixed words (Funnell 1987). Additionally, it should be noticed that when faced with pseudo-affixed words, our processing system nevertheless tries to impose some form of morphological structure on them (e.g. Longtin, Segui, and Hallé 2003).

However, Rastle, Tyler, and Marslen-Wilson (2006) conjectured that particular aspects of Funnell's (1987) study would necessitate certain validations. For instance, the three groups (truly affixed, pseudo-affixed, and embedded words) were not matched for imageability and frequency between the (perceived) stem and the correct word. Consequently, Rastle and colleagues re-investigated this matter by using the case of a different deep dyslexic patient (DE). DE was a 45-year-old individual who had a motor accident when he was 16, which resulted in brain trauma and severe language disabilities as a consequence. Rastle, Tyler, and Marslen-Wilson (2006) presented 52 genuinely suffixed (e.g. *childish*), 62 pseudo-suffixed words (e.g. *beaker*), and 61 embedded words (e.g. *addict*) plus 125 filler words about which DE had to make a lexical decision. Importantly, the three groups (genuine, pseudo, embedded) were closely matched on aforementioned important factors such as frequency and imageability for both the whole word and the stem separately. DE was tested in two sessions and was shown to make numerous errors spread over semantic (e.g. *lotion–cream*), visual (*haggle–haggis*), and morphological (e.g. *childish–child*) errors (and their combinations). In addition, he created various morphologically complex non-words (e.g. *goddess–*godery*). Contrasting with the previous results by Funnell (1987), the data by Rastle, Tyler, and Marslen-Wilson (2006) demonstrated that the genuinely suffixed words yielded significantly more stem errors than the other conditions (i.e. pseudo-suffixed and embedded words). Therefore, they concluded that these particular errors were not simply a form of visual error (which would have included the addition or subtraction of letters to obtain a word higher in frequency or imageability) but rather reflect that the lexical system has a form of organization which takes into account the morphological structure of complex words.

28.2.2.3 *Electrophysiological studies on the comprehension of derived words*

When studying complex word derivations, scholars are typically interested in how particular words are parsed on the basis of other existing words (e.g. is *loneliness* parsed by accessing the word *lonely*, is it a separately stored representation?). Typical ways of studying this is by using overt priming paradigms. This involves a particular (prime) word being shown and response time and accuracy to a subsequent target being measured. If the words share a morphological relationship, the response latencies are sped up for the target compared to when they do not. In this way, it has been shown that the derivation of a particular word depends on its semantic relationship with the base word. In other words, a word like *casualty* would not be accessed with the help of the target *casual* (e.g. not *casual* + *ty*) but the prime *casually* would be as it shares a semantic relationship and will need to access the base morpheme (the target), via *casual* + *ly* (see Tyler, Marslen-Wilson, and Waksler, 1993). However, as response latencies represent the endpoint of the cognitive processes underlying them, electrophysiological measures allow for a peek inside what is happening before the response is made. For a comprehensive overview of ERP studies (between 2006–2015) investigating complex word derivations see Smolka, Gondan, and Rösler (2015: Table 1).

Contrasting the previous results, Smolka, Gondan, and Rösler (2015) investigated semantically compositional derivations using the EEG/ERP technique. In particular, these authors were interested in the time course of morpho-lexical processing for German verbs, particularly when different processing stages (e.g. phonological form/semantic/morphological processing) occur and how any interaction between stages would take place. In an overt visual priming experiment, ERPs were obtained for target verbs (e.g. *sprechen* 'to speak') which were preceded by purely semantically related verbs (*reden* 'to talk'), morphologically and semantically related verbs (*ansprechen* 'to address'), and morphologically related but semantically unrelated verbs (*entsprechen* 'to match'), orthographically related verbs (*sprengen* 'to blow'), and unrelated verbs (*biegen* 'to bend'). Looking at the N400 (an ERP component occurring about 400–600 ms after target onset typically attenuated by a semantic relationship between prime and target), Smolka, Gondan, and Rösler (2015) found that this component was strongly attenuated for semantically related verbs (*reden–sprechen* vs. *biegen–sprechen*; in line with previous studies) indicating automatic activation spreading through the semantic network. Additionally, semantically transparent derivations showed priming (e.g. *ansprechen–sprechen* vs. *biegen–sprechen*) but remarkably also semantically opaque derivations showed N400 attenuation (e.g. *entsprechen–sprechen* vs. *biegen–sprechen*). Moreover, Smolka, Gondan, and Rösler (2015) reported that the N400 attenuation for opaque derivations was as strong as that for semantically transparent derivations contrasting earlier studies who did not obtain any priming for their opaque conditions (e.g. Kielar and Joanisse 2011). These findings indicate that the structure for German verbs refers to the base form irrespective of semantic composition. In other words, although *entsprechen* (to match) is semantically unrelated to *sprechen* (to speak), it does seem to access the latter verb as its base form (i.e. its constructed as *ent* + *sprechen*). This surprising ERP result awaits replication and verification but is nevertheless quite informative for the ongoing debate on how morphological derivations can be construed.

28.2.2.4 *Electrophysiological studies on compound comprehension*

Although a lot of attention has been drawn to the neural underpinnings of inflections and derivations, only few ERP studies report electrophysiological evidence concerning the comprehension of compound words. In one study, Koester et al. (2004) carried out several experiments in which German compound words were auditorily presented while the EEG was recorded. In their first experiment, they manipulated the grammatical gender agreement between the determiner and the first and final constituent of compound words (which were the modifier and head, respectively) to create four conditions. For example, in (1) *der*$_{\text{M}}$ *Regen*$_{\text{M}}$*tag*$_{\text{M}}$ (‘the rainy day’), the masculine determiner (*der*) is in agreement with both constituents (i.e. both are masculine). However, in (2) **der*$_{\text{M}}$ *Reis*$_{\text{M}}$*feld*$_{\text{N}}$ (‘the rice field’), they are not in agreement. For singular German compound words, the head establishes the correct determiner to be used (i.e. *das*). Therefore, in (2) *der* would be the incorrect determiner. Koester et al. (2004) also manipulated the agreement between the determiner and the first constituent. For example, in (3) *das*$_{\text{N}}$ *Presse*$_{\text{F}}$*amt*$_{\text{N}}$ (‘the press office’), the determiner *das* is correct as it corresponds with the head (both neuter); however, it does not correspond with the modifier’s gender (feminine). Lastly, in (4) **das*$_{\text{N}}$ *Nuss*$_{\text{F}}$*baum*$_{\text{M}}$ (‘the nut tree’) the determiner *das* is both incongruent with the gender of the modifier and the head. Although only the head is morpho-syntactically significant in German, both the head and the non-relevant modifiers elicited a left-anterior negativity (LAN-effect) in incongruent gender-determiner conditions (see also Koester, Gunter, and Wagner 2007). This finding, according to Koester and colleagues, clearly suggests that the internal morphological structure of German compound words is processed during auditory language comprehension. Additionally, they proposed that dual-route models most readily explain their findings (corroborating Penke et al. 1997 and Rodriguez-Fornells et al. 2001).

El Yagoubi et al. (2008) reported a lexical decision study that investigated the processing of compound words (with a particular focus on headedness). In English (as in many Germanic languages), the headedness of compound words is quite regular and can typically be determined by a rule. However, in other languages, including Italian (the language used by El Yagoubi et al. 2008), compounds have irregular headedness, allowing for novel experimental ways to distinguish between models which investigate compound processing (i.e. full-listing, full-parsing, and dual models). In Italian, the head can be located in the initial part or the final part of a compound, for example, *acquavite* (‘brandy’) is left-headed (i.e. *acqua* or ‘water’ is the head) and *filobus* (‘trolleybus’) is right-headed (i.e. ‘bus’ is the head).

In their experiments, El Yagoubi et al. (2008) created four conditions: genuine compounds with either the head in the left- or the right-hand position (e.g. *acquavite* or *filobus*) and embedded (non-compound) words with an existing word embedded in the left-hand (*salamandra* 'salamander' with *sala* 'hall') or the right-hand position (*accidente* 'accident' with *dente* 'tooth'). The non-words for the task were generated by swapping the two morphemes of a compound word or two sections of a non-compound word (e.g. *filobus* → **busfilo*; *salamandra* → **mandrasala*). Participants got a warning/fixation (500 ms) after which a word or non-word appeared on the screen (maximally 3 s) to which they had to make a lexical decision by pushing a button. Each trial was followed by a 2 s inter-trial-interval before the next trial started. A continuous EEG signal was recorded from 28 electrodes on a head cap (following the 10/20 system). The results were as follows: first, behaviorally, genuine compounds were found to be processed differently than embedded words, with the former yielding longer reaction times and more errors. There was no behavioral effect of headedness. Secondly, concerning the EEG data, a larger N400 lexicality effect was obtained for embedded words (compared to compound words). The authors speculate that this may be due to the way they inverted the compound and embedded words' constituents to form the non-words. In the case of compound words, the two constituents both still had a meaning (e.g. the non-word *spadapesce* was derived from *pescespada* 'swordfish' and both *spada* and *pesce* are lexical items) whereas in the embedded words, only one constituent was a lexical item (e.g. the non-word *forosema* was derived from *semaforo* 'traffic lights' but *sema* is not a lexical item).

Next, a modulation of the components typically involved in morpho-syntactic processing (i.e. P600 and LAN) was found for compound words only (i.e. not for embedded words) which indicates that a morpho-syntactic representation of the constituents was formed. Finally, although there was no behavioral difference, right-headed Italian compound words yielded a larger posterior P300 effect. The authors speculated that as right-headed compounds are marked (non-canonical), although grammatically correct, they might require increased attentional resources compared to the canonical (left-headed) order, which would be reflected in the P300 (as its amplitude is related to the extent of attention involved in processing the relevant stimuli; El Yagoubi et al. 2008). These results were interpreted to be against full-listing models and in favor of a dual-route processing model allowing access to both whole-word and constituent information when processing compound words.

28.2.2.5 *Neuropsychological studies on compound comprehension*

Besides studying the processing of compounds in the brain of healthy people using electroencephalography, others have studied this topic by investigating people diagnosed with aphasia. For instance, Semenza, Luzzatti, and Carabelli (1997) sought to investigate whether compound words are parsed into their constituents during the course of lexical retrieval. Although earlier evidence from aphasic patients in Germanic languages already indicated that morphological information was obtainable while phonological information was not (Hittmair-Delazer et al. 1994), Semenza, Luzzatti and Carabelli (1997) argued that it was not clear whether Italian compounding would show the same patterns as German compounding because Italian may require more intricate processing steps. Specifically, what Hittmair-Delazer et al. (1994) found is that when naming words, aphasic patients often substituted compound word targets with compound semantic paraphasias (e.g. *Salzstreuer* 'salt shaker'–*Zuckerdose* 'sugar jar') and compound neologisms (e.g. *Windmühle* 'windmill'; **Schneemühle* 'snow mill') which suggests knowledge of the underlying compound structure. However, this was also true when producing opaque compounds (i.e. when it is impossible to derive phonology or morphology from a compound's meaning, e.g. *Schuhlöffel* 'shoehorn, lit. shoe-spoon'). In reply to these findings, Semenza, Luzzatti, and Carabelli (1997: 34) stated that morphological rules used in constructing German compounds are so simple they could perhaps remain available to aphasics. Conversely, Italian compounds have a far less regular structure, for example, both endo- and extrocentric compounds exist with varying headedness. As a consequence, Semenza, Luzzatti, and Carabelli (1997) investigated whether Italian compounds show different error patterns between aphasic subtypes. For instance, verb–noun type compounds (e.g. *portamonete* 'purse'; literally: 'carry coins') would be especially worthwhile to investigate as patients suffering from the Broca's aphasia subtype are known to omit verbs. Whether they would also omit verbs in verb–noun compounds is not known (Semenza, Luzzatti, and Carabelli 1997: 35). Moreover, it has been shown that patients suffering from Broca's aphasia compared to other subtypes (such as Wernicke's and anomic aphasia) have more difficulties in finding nouns to describe actions. To assess aphasics' performance, Semenza, Luzzatti, and Carabelli presented the Italian version of the *Aachener Aphasie Test* (AAT; Luzzatti, Willmes, and De Bleser 1996) to eighty-three patients who were unambiguously diagnosed as either having the Broca, Wernicke, or anomic subtype. By studying the responses to the words presented in this test (particularly observing error patterns related to compound constituent substitutions and neologisms), Semenza, Luzzatti, and Carabelli (1997) concluded that people who faced difficulties in retrieving compound words often did preserve morphological knowledge about the target words. Furthermore, knowledge pertaining to the specific type of compound (i.e. noun–noun, verb–noun, etc.) was also found to be preserved. According to Semenza, Luzzatti, and Carabelli (1997), this indicates the existence of a distinct stage of morphological processing in the brain that is different from phonology. Additionally, Broca's aphasics (opposed to the other groups) showed a much higher error rate for compounds containing a verbal constituent. As the compound itself was always a noun, this is a strong indicator that compounds are indeed construed according to their constituents.

More recently, Marelli et al. (2013) studied compound word processing by investigating a special group of dyslectics, namely those showing neglect dyslexia (ND). Patients diagnosed with ND usually show a lack of awareness of (and attention to) one side of a presented word. The most common reading errors for ND patients are usually omissions or grapheme substitutions in the neglected side of the word. Some patients simply omit the neglected part of the word (e.g. *yellow* becomes *low*) whereas others show preservation of word length and substitution of the neglected elements (e.g. *yellow* becomes *pillow*). As ND patients seem to be aware of higher-level properties of words such as the difference between non-words and words (Caramazza and Hillis 1990) as well as showing sensitivity to subword constituents' frequencies (Arduino, Burani, and Vallar 2002), it seems not to be a purely peripherally, visually-centered disorder.

To shed light on the discussion regarding whether compound words are stored in their full form or decomposed into their constituents (or whether compound processing operates in a dual-route way), Marelli et al. (2013) investigated patients having ND. They selected seven right-handed, right-hemisphere brain-lesioned patients suffering from left visual neglect. This entails that the left constituent in compounds would be mostly neglected. After clinically assessing the extent of participant's neglect, they were subsequently presented with words on a computer screen, which they had to read out loud (regardless of whether or not they were real words). Two sets of stimuli were created; one set contained 48 endocentric[1] compound words split up into 24 left-headed (e.g. *camposanto* 'graveyard') and 24 right-headed (e.g. *fotocopia* 'photocopy') compound targets. The second set consisted of non-words, which were created by substituting the leftmost constituent of the existing compounds with an orthographically similar word (e.g. *camposanto* 'graveyard' would become *lamposanto* 'flash+holy'). Marelli and colleagues were interested in examining whether left- vs. right-headed compounds and existing vs. non-existing compounds gave rise to diverging patterns of results. They found a significant effect of headedness, which indicates that participants were better able to read left-headed compounds than right-headed compounds (i.e. although they made many mistakes, words like *camposanto* were still read more accurately than words like *fotocopia*). This result indicates not only that constituents can be processed, even though they are in the neglected position but, importantly, that compounds' constituents are indeed processed separately in the brain, and that there seems to be a difference between the processing of heads and modifiers. Additionally, they found a significant effect between real compounds and non-existing compounds, the latter eliciting more errors for the left-hand constituents than for existing compounds (i.e. the left constituent in words such as *lamposanto* showed more errors than left-hand parts in words such as *camposanto*).

Lastly, in a post-hoc analysis investigating the effect of frequency on performance, Marelli et al. (2013) found that for real compounds the higher the frequency of the left constituent, the higher the chance it was produced correctly (conversely, no effects for right constituents were found). Additionally, there were no effects of lexical variables on non-existing compound words. The authors concluded that if no parsing of any kind were present (i.e. only full form processing), then it would have been hard to find constituent effects, let alone frequency or headedness effects for the left constituent. Additionally, left constituent effects only emerged if the constituent was part of a real compound word indicating a complex relationship between the compound as a whole and its constituents. As such, Marelli et al. (2013) suggested that this pattern is in agreement with dual-route (e.g. Schreuder and Baayen 1995) or multi-route models (e.g. Kuperman et al. 2009) which suggest that both the whole compound word and its constituents play a role during language processing.

28.2.3 Production of morphology

Morphological structure is likely to play a role in speech production as well, although models of language production have not provided a separate role for morphological processing for a long time. There is evidence from speech planning experiments demonstrating that information about the planning of upcoming morphemes yields larger advantages than pure form information (e.g. phonemes). For instance, when Roelofs (1996) compared the naming latencies of word sets including an overlapping morpheme (for instance,

---

[1] Endocentric here indicates that one of the two constituents is unambiguously the head.

bijnier, *bijrol*, *bijvak*; 'kidney', 'supporting act', 'subsidiary subject') to a set of words with the same amount of phonological overlap (for instance, *bijster*, *bijna*, *bijbel*; 'loss', 'almost', 'bible'), he found a significantly larger facilitation effect for the former compared to the latter group when compared to a set of words without phonological overlap. This led Roelofs (1996) to conclude that morphemes are planning units in the speech production process. Evidence from speech errors ('a floor full of holes' → 'a hole full of floors' or 'I carved a pumpkin' → 'I pumped a carven'; taken from Fromkin 1973; or former US president George Bush's infamous quote "they misunderestimated me") supports this claim. Derivational and inflectional morphemes can easily strand, suggesting that derivational affixes and word stems may be stored separately. Importantly, the lexical representation of words may include information about their morphological structure (see Schiller and Verdonschot 2015 for an overview). The work on derivation and inflection in the area of language production is mainly limited to studies on speech errors and aphasic patients. In the following, we will focus on work with on-line measures such as speech latencies, ERPs, and fMRI bold (blood oxygen-level dependent) responses regarding complex morpheme production.

Relatively recently, Zwitserlood and her colleagues developed a new paradigm to investigate effects of morphemic structures in speech production (Zwitserlood, Bölte, and Dohmes, 2000, 2002; Dohmes, Zwitserlood, and Bölte, 2004; Zwitserlood, 2004). This paradigm was first tested in German, a language notorious for its morphological productivity and feared for its multi-morphemic compounds such as *Rindfleischetikettierungsüberwachungsaufgabenübertragungsgesetz* (lit. 'meat-labeling-control-task-transition-law'). In their so-called *long-lag priming procedure*, a to-be-produced target picture (e.g. *Ente* 'duck') is preceded by a related or unrelated (control) prime word followed by a number of intervening trials (usually 7–10). Zwitserlood and her collaborators tested several related priming conditions, that is, words that were morphologically related, either transparently (*Wildente* 'wild duck') or opaquely (*Zeitungsente* 'false report', lit. 'newspaper duck'), or only phonologically but not morphologically related (*Altersrente* 'pension'; *ente* in *Altersrente* is not a morpheme). Primes were presented visually on the screen, interspersed with filler words and pictures. On each trial, one stimulus was presented (either a word or a picture) and participants were asked to name each stimulus they saw on the screen as fast and as accurately as they could. The result was that target pictures (e.g. *Ente*) were named significantly faster when they were preceded by a morphologically related prime word (e.g. *Zeitungsente–Ente*) but not when preceded by a phonologically related word (e.g. *Altersrente–Ente*; see Dohmes, Zwitserlood, and Bölte 2004). This effect was independent of the position of the overlapping morpheme (initial vs. final; Zwitserlood, Bölte, and Dohmes 2000). Since the priming effect is not phonological (no priming from *Altersrente* to *Ente* despite the presence of a phonological relationship) nor semantic (priming from *Zeitungsente* to *Ente* despite the absence of a semantic relationship) in nature, the authors suggested that the facilitation arises at a level of word form representation at which the prime words and the pictures activate the same word form, that is morphemic, representation different from the semantic-conceptual level and the phonological level. One may argue that these studies do not really investigate the production of morphologically complex forms since all target forms are simplex nouns. However, in the course of the experiment all stimuli, whether target, prime, or filler, are produced by the participants. Therefore, complex word forms are produced as well. Nevertheless, it may be desirable to replicate the experiment with morphologically complex targets in the future as well.

Koester and Schiller (2008) replicated and extended the effects found by Zwitserlood and colleagues in several recent studies carried out in Dutch. First, Koester and Schiller (2008) replicated the morphological priming effect behaviorally with Dutch materials. In a first set of target pictures, targets such as *ekster* ('magpie') were preceded by semantically transparent (*eksternest* 'magpie nest') and opaque (*eksteroog* 'corn'; literally 'magpie eye') morphologically related prime words. Transparent and opaque primes facilitated the naming of target pictures when compared to unrelated primes. In a second set of target pictures (e.g. *jas* 'coat'), primes were morphologically related (e.g. *jaszak* 'coat pocket') or phonologically, but not morphologically related (e.g. *jasmijn* 'jasmine'). Opposed to unrelated control primes, the morphologically related prime facilitated target picture naming. However, there was no long-lag phonological priming effect from *jasmijn* to *jas*. Transparent (*eksternest*) and opaque primes (*eksteroog*) yielded similar effects, and the position of the overlapping morpheme (modifier vs. head constituent) did not play a role, demonstrating that the facilitation effect is abstract to some extent.

Furthermore, in the Koester and Schiller (2008) study, not only behavioral but—in a separate session—also electrophysiological data from twenty-nine electrode sites were collected. Relative to a baseline (200 ms pre-stimulus) the mean amplitude ERPs were calculated. This was done separately for each participant and each condition. The resulting mean amplitudes were evaluated in the time window between 350 and 650 ms post stimulus onset. These mean ERP amplitudes were significantly less negative (i.e. reduced) when picture naming was primed by transparent and opaque compounds. However, the ERP amplitude did not differ when comparing the transparent and opaque conditions (see also Figure 28.1). Moreover, significantly less negative, i.e. reduced, ERP amplitudes were found when the transparent and the unrelated condition were compared for the second

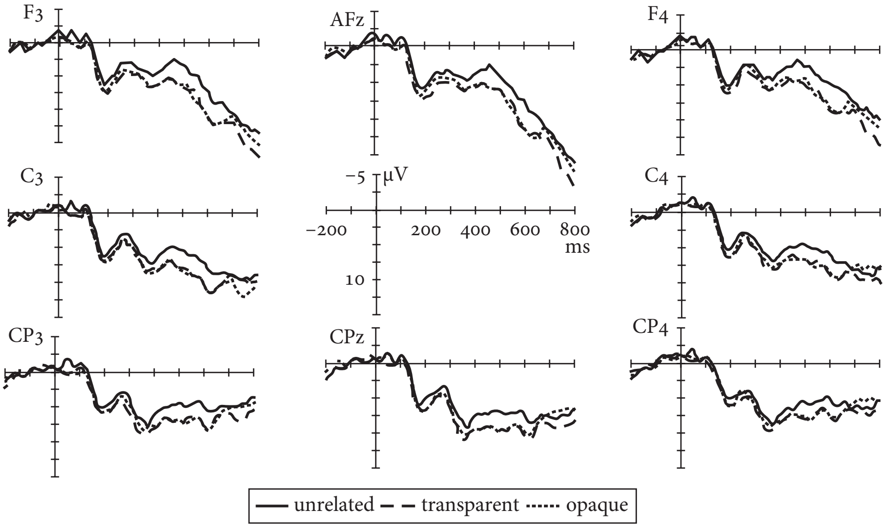

FIGURE 28.1. Grand average ERPs (negativity plotted upwards) in Set 1

The semantically transparent (dashed line), the semantically opaque (dotted line) and the unrelated conditions (solid line) are plotted superimposed on each other. ERPs are time-locked to the onset of the presentation of the picture.

Source: Köster and Schiller (2008).

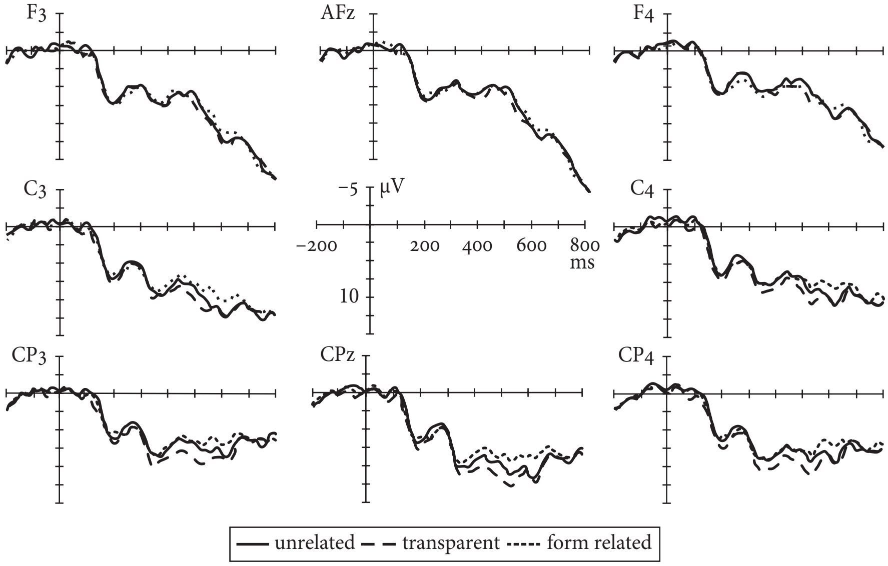

FIGURE 28.2. Grand average ERPs, superimposed for the morphologically related (dashed line: semantically transparent), the form overlap (dotted line), and the unrelated condition (solid line) in Set 2

The ERPs are time-locked to the onset of picture presentation, and negativity is plotted upwards.

Source: Köster and Schiller (2008).

set of pictures. In contrast, as shown in Figure 28.2, the form-related condition did not differ from the unrelated condition in that set. However, compared to the form-related condition, the transparent condition elicited less negative ERP amplitudes. Therefore, the pattern of behavioral responses was replicated by the ERP results. ERP amplitudes were consistently reduced between 350 and 650 ms after picture onset, most visibly at posterior scalp regions, when a morphologically related compound word (transparent or opaque) primed the naming of pictures, but not when picture naming was preceded by words that were merely form-related. Koester and Schiller (2008) proposed that this reduced negativity could be the reflection of an N400 effect because McKinnon, Allen, and Oosterhout (2003) demonstrated the sensitivity of the N400 effect to morphological processing in language processing.

The time course of these ERP effects agrees with estimates for morphological encoding during word production (Indefrey and Levelt 2004; Indefrey 2011). In contrast, semantic and/or conceptual processing begins around 175 ms after the presentation of a to be named picture. Once a lemma has been selected (around 250 ms after picture onset), the first process in word form encoding is morphological encoding, beginning about 330 ms after picture presentation (Indefrey and Levelt 2004). In the present study, the onset of the N400 effect is similar to the estimated onset of morphological encoding (i.e. 330 ms). Indefrey and Levelt (2004) assume a response latency of 600 ms; however, the mean response latencies in Koester and Schiller's study are around 650 ms. Accordingly, the onset of morphological encoding may be somewhat later (approximately 360 ms after picture onset), which is very close to the observed onsets of the N400 effects found in Koester and Schiller (2008). Therefore, the hypothesis that morphological priming during picture naming originates at a relatively late stage, namely during morphological encoding, is supported by the N400 effects. It seems that morphological priming effects can be located at the word form level (Indefrey and Levelt 2004).

A closer look at the scalp distribution of the N400 effects demonstrates that the two sets of stimuli in the transparent priming conditions differ in the Koester and Schiller (2008) study. Presumably, different subsets of materials may have resulted in different morphological priming. A more recent study by Koester and Schiller (2011) employed the current experimental design with another methodology, that is, functional magnetic resonance imaging (fMRI). The aim of that study was to determine more directly the neural substrate of the morphological priming effect in overt language production.

It has been suggested that N400 effects may be sensitive to morphological processing in comprehension tasks, such as visual word recognition (McKinnon, Allen, and Osterhout 2003). However, N400 effects have not previously been reported for morphological processing in overt picture naming studies. The amplitude of the N400 in visual word processing is reduced for related prime-target pairs compared to unrelated pairs. Jescheniak et al. (2002), for instance, used ERPs to investigate priming effects of implicit picture naming (covert preparation) on subsequent auditory word comprehension. Picture names that were semantically and phonologically related to the auditorily presented words resulted in less negative ERP amplitudes relative to unrelated picture–word pairs. These results demonstrate that the activation of semantic and phonological representations during the preparation of a picture name can be assessed by the influence of the activated information on subsequent word comprehension. Similarly, the current experiment demonstrates that processes in overt language production can be investigated with ERPs directly and reliably.

Koester and Schiller's (2008) results are robust and have been replicated in three studies so far. First, Verdonschot et al. (2012) investigated the question whether switching to another language before naming the target would interfere with the morphological priming effect. Bilingual Dutch–English participants named pictures preceded by a prime compound word in Dutch. Intervening filler items (words and pictures) were named either in Dutch (non-switch condition) or English (switch condition). If participants reactively inhibit the non-target language, one would predict longer naming latencies for the target pictures in the switch compared to the non-switch condition and a decreased morphological priming effect. However, morphological priming effects in the switch condition were of a similar magnitude as in the non-switch condition. Furthermore, both opaque and transparent compounds facilitated the naming of morphologically related target pictures, replicating previous findings in Dutch and German.

Second, Lensink, Verdonschot, and Schiller (2014) extended the Verdonschot et al. (2012) study to L2 production, that is, Dutch–English bilinguals naming target pictures in their L2, namely English, either in non-switch blocks (no intervening Dutch trials) or in switch blocks (including Dutch filler trials). Reaction times mirrored the effects of Verdonschot et al. (2012) very closely. Again, there were strong morphological priming effects in both switch and non-switch conditions and no significant difference in magnitude between transparent and opaque prime-target pairs. Therefore, Lensink, Verdonschot, and Schiller (2014) replicated previous studies in yet another language: English. Furthermore, they obtained reduced N400 effects in morphologically related conditions compared to an unrelated condition, however, only in the non-switch blocks. Presumably, participants applied a post-lexical checking strategy in the switch blocks, perhaps because the morphological relation between English prime and target was emphasized through the Dutch trials; this may have resulted in decreased N400 effects due to, for instance, better predictability of targets.

Third, Kaczer et al. (2015) extended earlier studies to novel Dutch compounds. Participants learned novel compound words, formed through the combination of two existing morphemes (e.g. *appel* + *gezicht* literally 'apple face'), in a first session. Novel and familiar (e.g. *appelmoes* 'apple sauce') compounds were used as primes in a long-lag priming paradigm for morphologically related target pictures (e.g. *appel*). A second session was recorded 48 hours after the first to investigate the effects of memory consolidation for the novel compounds. On a behavioral level, novel compounds initially showed a stronger priming effect than familiar compounds. This advantage was also present in simultaneously acquired EEG data, that is, a decreased N400 effect in morphologically related conditions compared to unrelated conditions, but the difference vanished two days after learning. This result may suggest that the novel compounds are initially processed as separate constituents. The change of the pattern after two days could reflect the consequence of a memory consolidation process that may help to assemble two initially separate words into a single unit. Therefore, the distinction between decomposition of the compound word and full parsing could depend on the integration of the novel compounds into the mental lexicon. Alternatively, the novel compounds may cause an increase in the attentional resources needed for reading aloud, which could have contributed to a more effective decomposition of their constituents.

Methodologically speaking, the exclusion of trials and participants due to (eye) movement artifacts is a major issue when employing ERPs to overt language production tasks. Relatively strong ERP components such as the error-related negativity (ERN) may suffer less when the number of trials is reduced (Falkenstein et al. 1990; Ganushchak and Schiller, 2006, 2008). The present overt picture naming study demonstrates that even less strong ERP components can be detected reliably (see also Christoffels, Firk, and Schiller 2007; Ganushchak, Christoffels, and Schiller 2011; Timmer and Schiller 2014).

In a following step, Koester and Schiller (2011) aimed to investigate the neuro-anatomical correlates of morphological processing. Indefrey (2011; see also Indefrey and Levelt 2004) investigated the brain areas that are associated with different processing stages in language production. On the basis of this meta-analysis, Indefrey and Levelt (2004) localized phonological code retrieval in the left posterior superior and middle temporal gyri. One may predict morphological priming to affect neural activity in the left posterior superior and middle temporal gyri (MTG) if morphological information affects phonological code retrieval. Previous studies investigating language production examined several inflectional mechanisms such as plural formation of nouns or first and third person verb generation (e.g. Jaeger et al. 1996; Beretta et al. 2003; Joanisse and Seidenberg 2005). Results of these studies are often unspecific as to whether they reflect processes of comprehension or production because linguistic stimuli were presented to elicit a verbal response. That is why comprehension and production processes are difficult or impossible to disentangle. Other neuroimaging studies on language production, that is, studies that avoided influences from comprehension processes, did not investigate morphological processing (e.g. De Zubicaray and McMahon 2009; Kan and Thompson-Schill 2004).

In their own study, Koester and Schiller (2011) investigated the neurocognitive correlates of morphological processing in the human brain by employing a long-lag priming paradigm. The paradigm was very similar to the one used in the ERP study reported in Koester and Schiller (2008). Participants were requested to read prime words, that is compounds, aloud and, seven to ten trials later, they overtly named picture targets. During a given trial, only one stimulus—a word or a picture—is presented on the screen. Therefore, target picture naming does not coincide with reading aloud the primes. The long-lag priming paradigm has been shown to be sensitive to morphological, but not semantic or phonological relations between primes and targets (Feldman 2000; Zwitserlood, Bölte, and Dohmes 2000). Behavioral analyses revealed that morphologically related compound words facilitated picture naming. Just as in previous research, semantically transparent and opaque conditions did not differ, and the form-related condition did not produce a facilitation effect. Overall, this data pattern is very similar to previous morphological priming effects in the production of compound words (Dohmes, Zwitserlood, and Bölte 2004; Koester and Schiller 2008; Zwitserlood, Bölte, and Dohmes 2002). On a neurocognitive level, Koester and Schiller (2011) found in a conjunction analysis, that is, taking into account activations specific to both transparent and opaque primes, that morphological priming effects are related to specific neural activity in the left inferior frontal gyrus (LIFG), specifically Brodmann area 47 (Figure 28.3). Morphological priming in picture naming led to increased neural activity in that area. This result underlines the functional importance of LIFG for morphological processing in language production and it contributes to the understanding of an elementary mechanism of word formation, that is compound processing. Thus, these results support the prediction for LIFG but not for the left posterior MTG.

In summary, Koester and Schiller (2011) used fMRI to investigate the processing of morphological information in speaking. Morphological priming in picture naming led to increased neural activity in LIFG (BA 47). It may be speculated that increased neural activity in this area may be responsible for the decreased N400 effect in the ERP studies reported in this section, possibly indicating less processing or integration effort. This result underlines the functional importance of LIFG to word form encoding and for morphological processing in language production and calls for further investigations of the neural

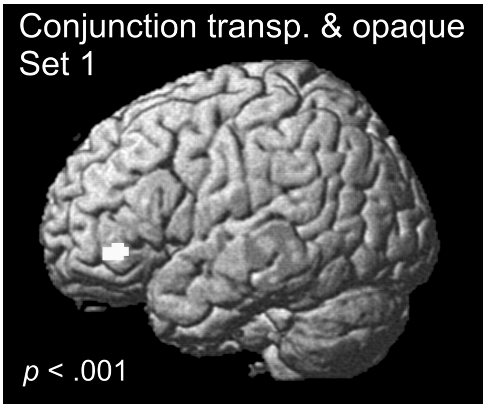

FIGURE 28.3. Surface rendering of regions activated by transparent and opaque priming conditions in Set 1

Conjunction analysis; $p < 0.001$, uncorrected; $k = 0$. Activations are superimposed on a standard single subject MNI template.

Source: Köster and Schiller (20011).

correlates of language production. More specifically, these results bear relevance to the understanding of compound processing, an elementary mechanism of word formation.

28.3 Future directions

Here, we discussed the way words and morphemes are accessed in our mental lexicon when we translate thoughts into speech or comprehend the speech of others. We discussed the lexical representation of morphologically complex words. We saw that a full-form representation of morphologically complex words yields substantial problems and maybe is to be considered implausible. Rather, it seems that we store complex words in terms of their constituting morphemes, and that the morphological relation between (parts of) words is particularly strong, even in a second language, for novel compounds, or after switching between different languages.

In the future, we will need to develop more experimental paradigms to investigate morphological processing both in language comprehension and production using different methods of experimentation. One well-investigated and robust paradigm is the long-lag priming paradigm that we described in §28.2.3. This paradigm has proven to yield consistent and replicable results across experimental methods (behavioral, electrophysiological, and hemodynamic) and across languages. Based on these properties, we were able to learn a lot about the neurocognitive representation and processing of a particular type of complex words, that is compounds. However, one may claim that compounds are a special case of complex words, and that derivations and inflections have other grammatical constraints, which may yield different results than compound processing. Therefore, it will be important to develop ways to investigate these morphological processes as well.