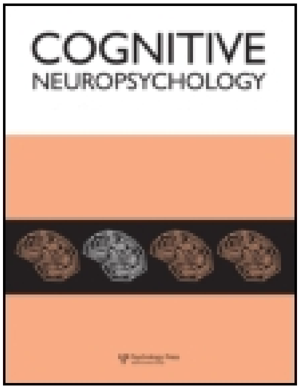

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When do combinatorial mechanisms apply in the production of inflected words?

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When do combinatorial mechanisms apply in the production of inflected words?

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A central question for theories of inflected word processing is to determine under what circumstances compositional procedures apply. Some accounts (e.g., the dual-mechanism model; Clahsen, 1999) propose that compositional processes only apply to verbs that take productive affixes. For all other verbs, inflected forms are assumed to be stored in the lexicon in a nondecomposed manner. This account makes clear predictions about the consequences of disruption to the lexical access mechanisms involved in the spoken production of inflected forms. Briefly, it predicts that nonproductive forms (which require lexical access) should be more affected than productive forms (which, depending on the language task, may not). We tested these predictions through the detailed analysis of the spoken production of a German-speaking individual with an acquired lexical impairment resulting from a stroke. Analyses of response accuracy, error types, and frequency effects revealed that combinatorial processes are not restricted to verbs that take productive inflections. On this basis, we propose an alternative account, the stem-based assembly model (SAM), which posits that combinatorial processes may be available to all stems and not only to those that combine with productive affixes.

Keywords: Morphology; Inflections; Productivity; Affixation; Speech production; Neuropsychology.

Linguists have long recognized that a major distinction can be drawn in a number of languages between inflected words with predictable versus idiosyncratic forms. The past tense of English verbs is a commonly cited example of such distinction. Most English verbs are obtained by adding the suffix −*ed* to a stem (*walked*, *painted*), a pattern not exhibited by a few English verbs that

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instead have past tenses like *sang* and *gave*. The existence of these two types of inflected forms naturally raises the question for processing theories of language of whether a parallel distinction exists at the level of the (neuro)cognitive processes that generate inflected word forms. Current processing theories generally agree on the existence of distinct processes for the two types of inflection, although there is important variation in the implementation of such processes (Clahsen, 1999; Marcus, 2001; Marlsen-Wilson & Tyler, 1997; Pinker, 1991, 1999; Ullman, 2001). In the present study we focus on a specific theory: the dual-mechanism model (DMM; Clahsen, 1999; Clahsen, Eisenbeiss, Hadler, & Sonnenstuhl, 2001; Sonnenstuhl, Eisenbeiss, & Clahsen, 1999). DMM is appealing not only for proposing one of the most detailed accounts of the cognitive mechanisms of word inflection, but also for providing an account of inflectional systems that vary in complexity—from the relatively simple case of English to the more complex case of German.

An important distinction is made under DMM between inflected words generated by combinatorial mechanisms that concatenate stems to the suffix and inflected words stored in the lexicon. With respect to English verbs, the theory holds that "regular" past tense forms like *walked* or *painted* are the product of combinatorial mechanisms, whereas "irregular" past tense forms like *sang* and *gave* are forms stored in the lexicon. Crucially, DMM proposes that the application of combinatorial versus lexical encoding processes is largely determined by the *productivity* of an affix, such that affixation is only allowed with inflected forms of verbs that take the productive or default affix, while inflected forms of verbs that take nonproductive affixes are generated within a lexical network, as explained in more detail below. In this paper, we use cognitive neuropsychological data to evaluate predictions of DMM for German past participle formation. We argue that the results we obtain are problematic for certain aspects of the DMM, and we propose an alternative account that we refer to as the *stem-based assembly model*. In contrast to the DMM, we propose that combinatorial affixation processes are not restricted to verbs that take productive inflection, but instead apply more broadly to all stems in the lexicon that are specified as taking an affix.

Productivity, regularity, and the case of the German past participle

We use the term productivity as a descriptor that applies to affixes and regularity as a descriptor that applies to word categories (e.g., verbs or nouns). They are, at times in the literature, used interchangeably (see Bauer, 2001, for a review of the use of these terms), but we attempt to systematically apply them in this manner. Because this investigation concerns verbs, we refer specifically to verbs in our discussion—however, we assume that the same points apply to other word classes that undergo affixation.

A number of factors are usually considered in evaluating the productivity of an affix. Typically, this includes considerations such as the number of different verbs it applies to (type frequency) and whether or not it is used as the default form as determined by several diagnostic features such as its use in borrowings, onomatopoeia, and denominal verbs (Bauer, 2001; Clahsen, 1999; Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995). Also considered is experimental evidence regarding the affix/es that speakers use when they are asked to inflect novel forms (e.g., Clahsen, 1997; Prasada & Pinker, 1993).

The conditions for the application of the terms regular/irregular are less clear or uniform. For example, the terms have been used to distinguish between verbs that have only one stem form in their paradigm versus those that have multiple stems (e.g., Cutler, 1980; Dressler, 1985), between verbs that take the productive affixes versus those that do not (e.g., Bloomfield, 1935; Marcus et al., 1995), or both (e.g., Pinker & Price, 1988). In addition, regularity has been defined as a feature of the computational mechanism that combines morphemic constituents (Pinker, 1991).

The English past tense represents a relatively straightforward case in which the use of productive affixes and invariant stems largely coincides. With regard to affix productivity, in the English past tense the suffix −*ed* occurs with the majority of English verbs, it is almost invariably applied to borrowed words (Pinker & Price, 1988) and denominal verbs (e.g., Kim, Pinker, Prince, & Prasada, 1991) and is typically used in experimental settings with novel forms (Prasada & Pinker, 1993; Ullman, 1999). These factors indicate that the "stem + ed combination" is productive and used by default. With regard to regularity, English verbs that maintain the same stem in the past tense take the −*ed* inflection (with rare exceptions, e.g., *put*). And, similarly, verbs that undergo stem changes in the past tense do not take the −*ed* inflection. Therefore, in the English past tense, there is one predominant type of stem−suffix combination, and, for this reason, there is a relatively straightforward mapping between the regular/irregular distinction and productive/nonproductive affixation. However, across languages there are many examples of word classes for which multiple types of stem−affix combinations coexist. In these cases, the determination of productivity, regularity, and the circumstances under which the application of combinatorial mechanisms takes place may not be as clear-cut. A case in point is offered by the German past participle, the focus of this investigation.

In the German past participle there are five different types of stem type−suffix combinations. These combinations occur with unequal frequencies in the German language, and only one of them is productive in the sense of being used by default with novel words and borrowings. For these reasons, the German past participle may allow us to investigate whether stem + suffix morphological assembly is restricted to the productive inflection, or whether other considerations are relevant, and assembly applies more broadly. Note that although we are only considering the German past participle, the conclusions we draw have implications that are broader in scope, with relevance for the inflectional systems of other languages.

Several notations have been proposed for German verb categories; here, we refer to the one introduced by Paul (1916, 1998). This notational system is based on the fact that individual verbs may take different stems in the following three tenses: infinitive, past tense (preterite), and past participle. The notation refers to the stems of each of these tenses and indicates whether or not the stems vary across tenses. As illustrated in Table 1, there are five types of verbs, which we group into three categories: (a) AAA, (b) ABA, and (c) ABB and ABC (also part of the third group are the so-called *mixed verbs*). Type counts for the different verb categories are reported in Table 1. Given that our experiment concerns the past participle, we present details regarding this specific tense in this review.

1. The AAA verbs keep the infinitive stem (indicated by the letter A in this notation) in all three tenses. In addition, AAA verbs take the suffix −*t* in the past participle. Thus, the AAA verb *fragen* [to ask] preserves its infinitive (A) stem −*frag* in its past participle *gefragt*, which contains the prefix *ge*− and the suffix −*t*. (The prefix *ge*− occurs in any German past participle form bearing the main stress on the first syllable, a prosodic pattern exhibited by most German verbs; this prefix is not relevant at this point in our discussion.)
   The verbs in each of the other four categories have more than one stem in their paradigms and—with few exceptions—take the suffix −*en* in the past participle.
2. ABA verbs take the infinitive stem in the past participle, changing it only in the past tense (B). For example, the ABA verb *raten* [to guess] changes the infinitive stem (*rat*−) in the preterite (*riet*−) but keeps the infinitive stem in the past participle (ge*rat*en).
3. In contrast to AAA and ABA verbs, the other three verb categories all involve stem changes in the past participle. These include ABB or ABC verbs, which differ in terms of whether the past participle shares the stem (B) with the preterite or takes a different stem (C; see Table 1 for examples). The verbs of the third type within this group—referred to as *mixed verbs*—undergo stem change, but unlike the

Table 1. *Types of German verbs with representative examples*

	Verb inflection				
			Past participle		
Verb category[a]	*Infinitive stem*	*Past tense stem*	*Stem*	*Suffix*	*N*
AAA	*fragen* [to ask]	*fragte*	*gefragt*		1,700
	frag	*frag*	*frag*	$-t$	
ABA	*raten* [to guess]	*riet*	*geraten*		41
	rat	*riet*	*rat*	$-en$	
ABB	*fliegen* [to fly]	*flog*	*geflogen*		144
	flieg	*flog*	*flog*	$-en$	
ABC	*werfen* [to throw]	*warf*	*geworfen*		(ABB + ABC)
	werf	*warf*	*worf*	$-en$	
Mixed	*brennen* [to burn]	*brannte*	*gebrannt*		15
	brenn	*brann*	*brann*	$-t$	

Note: $N =$ type counts of noncompound verbs (from Smolka et al., 2007) based on CELEX (Baayen et al., 1993).
[a]The letters in the verb category notation (Paul, 1916, 1998) correspond to the stems that verbs take in three inflections: A = infinitive, B = past tense, C = past participle. For example, the notation AAA specifies that the verb bears the infinitive stem in all representative inflections, whereas the notation ABC indicates that the verb takes three different stems.

other verbs exhibiting stem change, they take the suffix $-t$ in the past participle. An example is *gebrannt* [burnt]: It takes the suffix $-t$ and the stem *brann*, which differs from the basic stem *brenn* of the infinitive *brennen* [to burn].

Two features of German verbs should be noted. First, the category that a verb corresponds to cannot be reliably predicted on the basis of the semantic or phonological features of the verb (Durrell, 2001; Wiese, 1996a). Second, stem changes always involve the vowels and in a few cases also the consonants (Wiese, 1996a).

With regard to productivity criteria, the suffix $-t$ found in the past participle of AAA verbs has the largest type frequency in the German language[1] (see data in Table 1) and constitutes the default form, as attested by several diagnostic features. For example, the suffix $-t$ appears in borrowings, onomatopoeia, and denominal verbs (Clahsen, 1999; Marcus et al., 1995). There is also experimental evidence that the suffix $-t$ is typically used as the productive, default form when German speakers are asked to indicate the past participles of novel verbs (Clahsen, 1997; novel verbs rhyming with existing ABB or ABC verbs are often an exception: The suffix −en is preferred for these verbs). With regard to regularity, AAA verbs have been typically labelled as *regular*, while all of the other verb categories have been referred to as *irregular*. This distinction was based on the notion that regular verbs only have one stem in their paradigm, while irregular verbs have multiple stems. However, it is clear from the discussion just above that, in German, there is a not a straightforward mapping of productive affix use and stem uniformity. For example, although ABA verbs do not take the productive affix, their stems exhibit some degree of uniformity and thus occur in many tenses, including the past participle. On the other hand, mixed

[1] The AAA past participles are clearly predominant in large corpora such as CELEX (Marcus et al., 1995). In smaller corpora that only include the most frequent words, past participles taking the suffixes $-t$ and $-n$ have a more balanced distribution, in terms of both type and token frequencies (Clahsen, 1999; Marcus et al., 1995).

verbs take the productive affix but lack stem uniformity. Given this fact, German provides opportunities, as Marcus et al. (1995) have argued, to decouple productivity and regularity and therefore examine the organization and functioning of the system of word affixation and production.

In the next sections we review the proposal for the processing of morphologically complex words advanced by Clahsen and collaborators (e.g., Clahsen, 1999); we then outline an alternative account and then end with a discussion of predictions that may help to adjudicate between them.

The dual-mechanism model

Minimalist morphology, a linguistic theory introduced by Wunderlich and Fabri (1995; see also Wunderlich, 1996) proposes two distinct mechanisms of word formation: affixation for productive (regular) inflectional forms and structured lexical entries for unproductive (irregular) inflections. The reason for introducing this distinction is that only productive patterns are typically generalized to novel words. Like other minimalist approaches in linguistics, minimalist morphology adopts a small number of principles and constraints and makes extensive use of underspecification. General principles underlie the processing of both productive and unproductive inflectional forms. Minimalist morphology provided a theoretical framework for the *dual-mechanism model* (DMM), a psycholinguistic processing account offered by Clahsen (1999). This model proposes specific cognitive mechanisms of inflection in German and English.

Consistent with the minimalist morphology approach, the DMM distinguishes between lexically based inflected forms and inflected forms generated by affixation processes. To illustrate the functioning of the model we can consider the case of English past tense and past participle. According to DMM, regular verbs each have a single base node that corresponds to what Wunderlich (1996) refers to as the basic stem. The past tense and past participle are produced by affixation processes that take the syntactic and phonological content of the basic stem as input and combine it with the appropriate suffix −*ed*. In contrast, irregular verbs are produced by accessing the base node and retrieving the inflected form, which is recovered from the lexical representation through the inheritance tree structure (see Figure 1). Each node in these structured lexical representations is devoted to a different morphological form of the word (e.g., one node each for: the basic stem *sing*, its past tense form *sang*, and its past participle form *sung*). Nodes lying at the lower levels of the structured lexical representations inherit the syntactic and phonological features from higher nodes; they only encode the

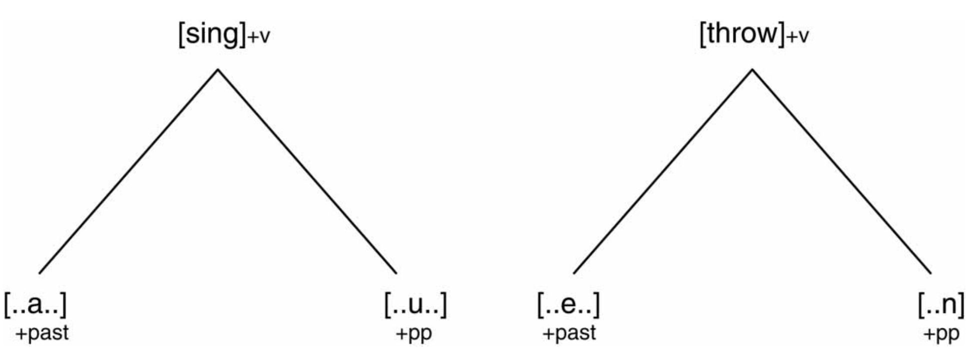

Figure 1. *Schematic depiction of the structured lexical entries proposed in minimalist morphology for irregular English verbs and adopted by the dual-mechanism model (DMM). The different inflections of irregular verbs are represented within hierarchical structures. The verb base form (*sing, throw*) is represented by the top node; the irregular verb inflections (*sang/sung; threw/thrown*) are represented by subordinate nodes. Subordinate nodes inherit the syntactic and phonological features from higher nodes. v = verb, past = past tense, pp = past participle. Adapted with permission from Wunderlich, D. (1996). Minimalist morphology: The role of paradigms. In G. E. Booij & J. van Merle (Eds.).* Yearbook of Morphology 1995 *(pp. 93–114). New York, NY: Springer. Copyright 1996 by Kluwer Academic Publishers.*

features that change specifically for a given form. For example, the node corresponding to *sung* simply indicates the vowel difference between this form and the basic stem form—all other features are inherited from the *sing* node. Each node in a structured lexical entry constitutes a pair of phonological string + morphological feature values.

A similar type of representation is proposed for German irregular verb inflections (Wunderlich, 1996), as can be seen in Figure 2. For example, the subordinate node corresponding to the irregular past participle of the ABC-type verb *geworfen* [thrown] inherits the consonant skeleton /w−r−f/ of the basic stem *werf* and encodes two specific features for (ge−)*worfen*: its first vowel /o/ and its end syllable /en/. It is important to note that −*en* is embedded into the representation of the irregular past participle verb *geworfen*. That is, rather than being a suffix that is appended to the verb stem by combinatorial processes, −*en* is phonological material that is retrieved from the lexicon as part of a stored morphophonological form. The prefix *ge*− is attached by combinatorial processes. In addition, combinatorial processes apply to produce inflected forms of AAA verbs. Such processes take the base nodes stored in the lexicon as their input and combine them with the appropriate suffix −*t*.

Stem-based assembly model

We propose an alternative account (see Figures 3 and 4) that we refer to as the *stem-based assembly model* (SAM), a label capturing the assumption that affixation processes apply more broadly, without being limited to the productive or default affixes. Specifically, we propose that combinatorial affixation is available to all stems. This assumption is shared by other models of speech production (e.g., Levelt, Roelofs, & Meyer, 1999), which differ from SAM in other respects.

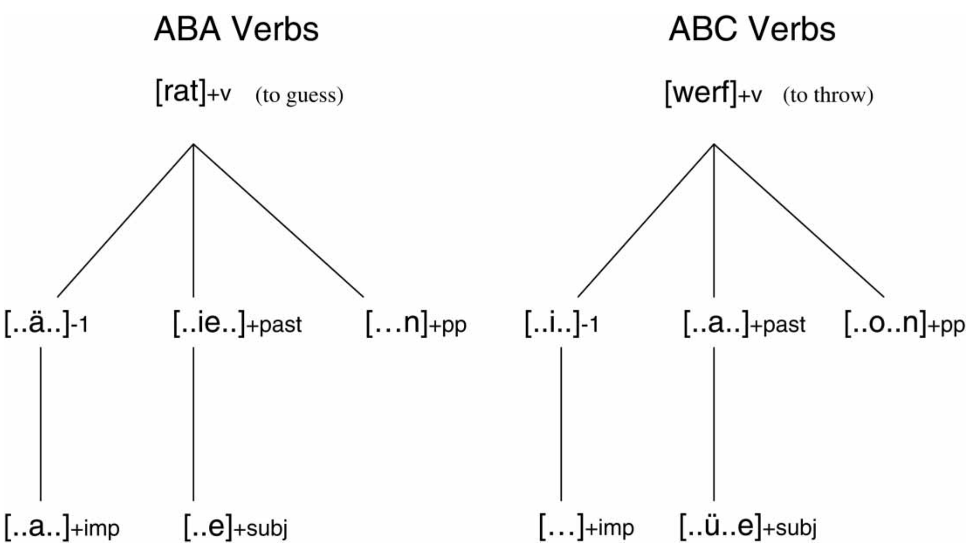

Figure 2. *Schematic depiction of the structured lexical entries proposed in minimalist morphology for irregular German verbs and adopted by the dual-mechanism model (DMM). The different inflections of irregular verbs are represented within hierarchical structures. ABA verbs:* raten *[to guess]; ABC verbs:* werfen *[to throw]. The lexical representations of each verb specify the syntactic and phonological features of the forms with nonproductive patterns. Note that (a) ABA and ABC past participles are represented in a similar fashion (as well as ABB, not shown here), and (b) information about the suffix* −en *is encoded within the lexical representations of these verbs. See text for further details. v = verb, −1 = indicates that the second (du wirfst [you throw]) and third person (er/sie/es wirft [he/she/it throws]) singular have a different stem from that of the first person (ich werfe [I throw]) singular in the present tense; past = past tense, pp = past participle, imp = imperative; subj = subjunctive. Adapted with permission from Wunderlich, D. (1996). Minimalist morphology: The role of paradigms. In G. E. Booij & J. van Merle (Eds.).* Yearbook of Morphology 1995 *(pp. 93–114). New York, NY: Springer. Copyright 1996 by Springer. Kluwer Academic Publishers.*

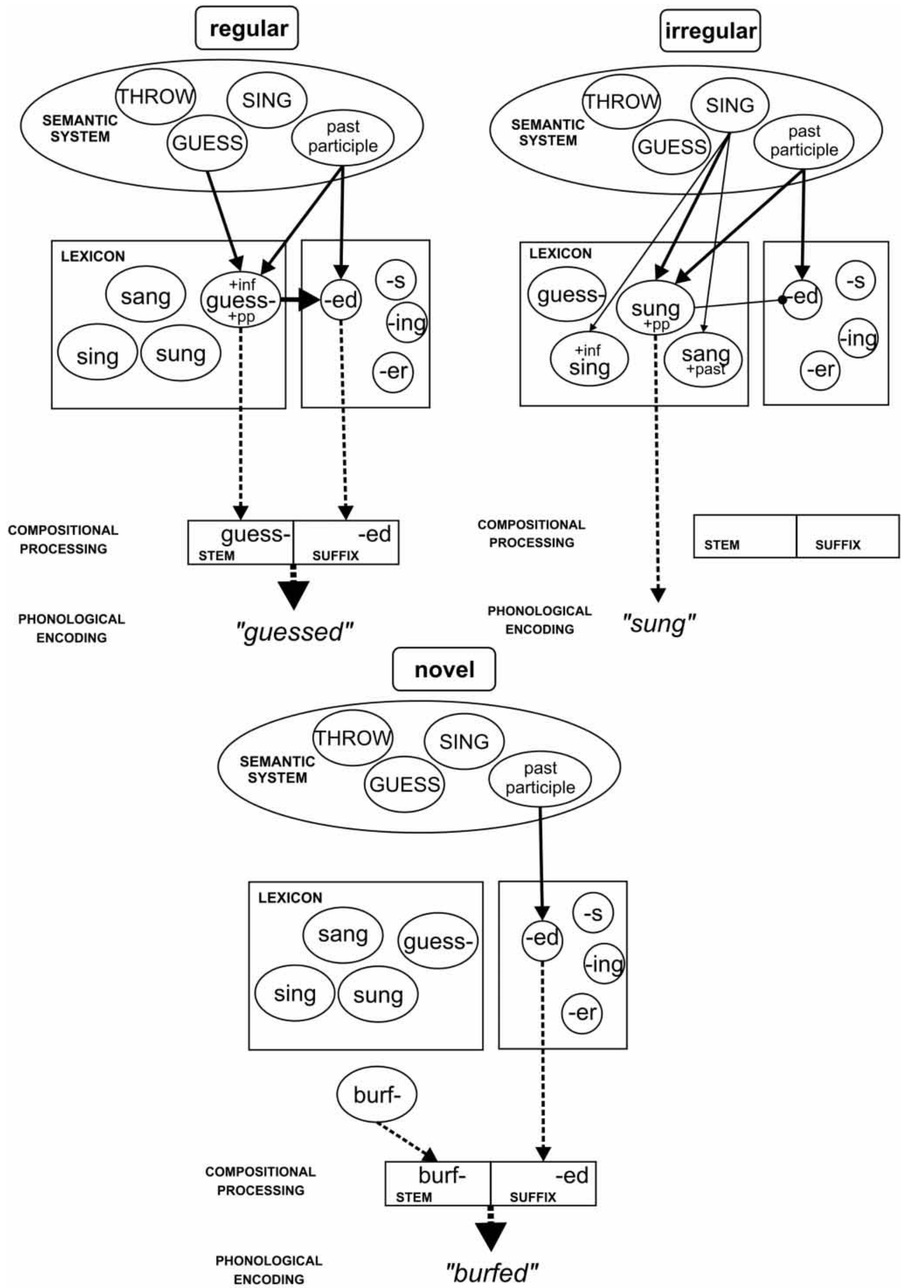

Figure 3. *Schematic depiction of the mechanisms that the stem-based assembly model (SAM) proposes for the production of English past tense and past participle forms. Regular inflections (*guessed*); irregular inflections (*sung*); and novel verbs (*burfed*). Verb stems are encoded in the lexicon, separately from suffixes. Lexical representations and affixes are activated by semantic and grammatical processes (the latter are not shown). Solid arrows indicate activation, with line thickness indicating degree of activation; dashed arrows indicate that a given representation has been selected; the line with a black, round endpoint indicates inhibition. The suffix* −ed *is always activated when a past participle form is required—but it is inhibited by irregularly inflected verbs (as shown for* sung*). See text for further details; +inf = infinitive, +past = past tense, +pp = past participle.*

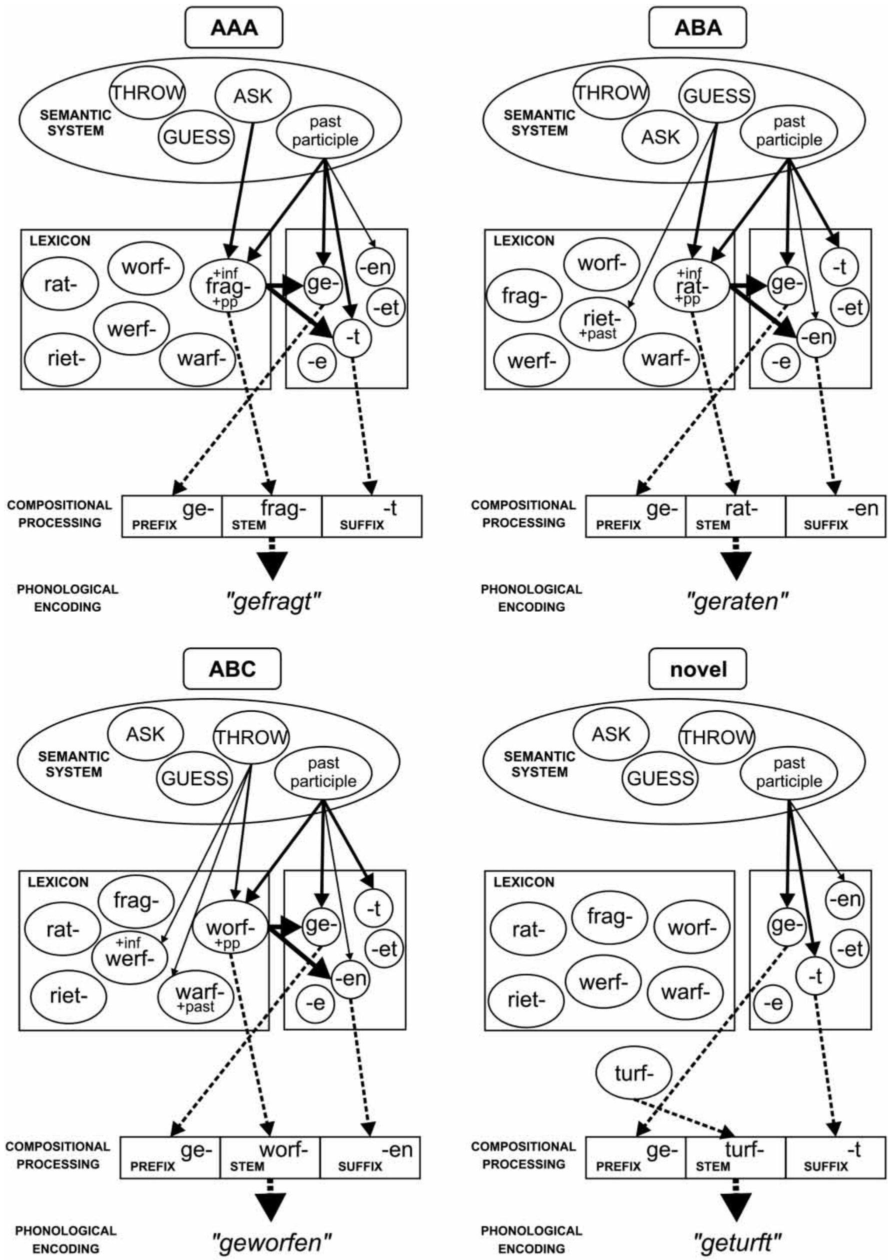

Figure 4. *Schematic depiction of the mechanisms that the stem-based assembly model (SAM) proposes for the production of German past participle forms. AAA past participles (e.g.,* gefragt *[asked]); ABA past participles (e.g.,* geraten *[guessed]); ABC past participles (e.g.,* geworfen *[thrown]); past participle of a novel verb (e.g.,* geturft*; suffix* −t *is expected). Lexical representations and affixes are activated by semantic and grammatical processes (the latter are not shown). Verb stems and suffixes are stored separately. Solid arrows indicate activation; line thickness corresponds to degree of activation; dashed arrows indicate that a given representation has been selected. Tense labels are included only for the stems under consideration in each example. Note that ABA and ABC (as well as ABB, not shown here) past participles are represented in the same fashion according to SAM. See text for further details; +inf = infinitive, +past = past tense, +pp = past participle.*

A comparison of SAM to other models of speech production is beyond the scope of the present report. Here, we focus specifically on the comparison between SAM and DMM.

Even if SAM differs from DMM in proposing a wider application of combinatorial processes, the two models share many other features. For example, in both SAM and DMM, the lexicon contains an entry for each verb that includes the basic stem form of the verb. However, there are a number of phenomena that DMM was developed to account for that are currently outside the scope of SAM (e.g., the processing of inflections in speech recognition).

Figure 3 shows the English variant of SAM. The figure illustrates the lexical entry for a regular verb such as *guess*, which includes its basic stem as well as links to the combinatorial operations that the verb can participate in. Figure 3 also provides an example of the irregular verb *sing*, whose entry includes the various stems of the verb (*sing*, *sang*, and *sung*). The lexical representations involved in morphological processing specify the phonological content of words. That is, the representation corresponding to the basic stem of *guess* encodes, among other things, the phonological spell-out of the stem and lexical determined prosodic features (e.g., stress).

In SAM, stems and bound morphemes are separately represented. This distinction is in part motivated by the acquired language deficits selectively affecting bound morphemes (Badecker & Caramazza, 1991; Badecker, Hillis, & Caramazza, 1990; Laine, Niemi, Koivuselkä-Sallinen, & Hyönä, 1995; Miceli & Caramazza, 1988) or stems (Badecker, Rapp, & Caramazza, 1996). Information encoded at semantic and syntactic levels of processing jointly specify the various parameters (e.g., tense, number) that are critical for the selection of the morphological constituents of the word. If, as illustrated in Figure 3, a speaker wants to produce the regular past participle form *guessed*, semantic and grammatical information activate the stem *guess*− and the suffix −*ed*. Further activation converges to −*ed* from the lexical entry of the stem *guess*−, as this entry specifies that it is a regular verb that combines with the productive suffix −*ed*. Under normal circumstances, the stem *guess*− and the suffix −*ed* are selected and are entered into combinatorial processing. Combinatorial processes will vary across languages, with simple concatenation in English and German and infixation in Hebrew or Arabic. As shown in Figure 3, the lexical entry corresponding to *sung* is activated when the past participle has to be produced. Semantic and grammatical processes automatically activate the productive suffixes. This is the feature of the model that is responsible for the default use of productive suffixes with novel words. To prevent its incorrect selection, −*ed* is inhibited by stems that do not enter into combinatorial processing; this is illustrated for *sung* in Figure 3.

For German, SAM assumes that each lexical entry contains the basic verb stem as well as all other stems including the B and C stems for ABA and ABC verbs (see Figure 4).

As in English, links to the combinatorial operations the verb can participate in are specified within the lexical entry. Stem selection is a function of the activation received from semantic and syntactic processes. Moreover, semantic, syntactic, and lexical information jointly determine which suffix is entered in the combinatorial process. In particular, semantic and syntactic information specify the parameters (e.g., tense, number) that the suffix has to satisfy, while lexical information constrains selection to the family of suffixes associated with a particular verb. Under normal circumstances, activation coming from semantic and syntactic levels of processing as well as from the verb lexical representation converges on the target suffix. The phonological information specified in the lexical entry would also trigger the activation of the suffix −*ge*, making it available for production in the appropriate phonological environments.

Combinatorial mechanisms integrate the selected stem with the selected suffix. Semantic and syntactic information activate all the suffixes that satisfy the critical parameters. Thus, both −*t* and −*en* are activated when speakers intend to produce the past participle form of a verb. However, more activation is received by the productive suffix (e.g., −*t* for the past participle), which ensures the default selection of the productive suffix with novel verbs.[2]

Though we focused our description of the production of past participle forms, it should be apparent that SAM can readily be employed for other tenses, including the past tense. Several features of SAM, however, remain unspecified. For example, the model does not make specific claims about allomorphic variants of −*ed* (/t/, /d/, /ət/) or whether suffix selection is affected by suffix frequency, such that more frequently used suffixes are activated more quickly than less frequent ones. Nonetheless, the core assumption of SAM—namely, that affixation applies extensively regardless of productivity and regularity—can still be tested.

Distinguishing between DMM and SAM: A cognitive neuropsychological investigation

A salient difference between DMM and SAM concerns the range of forms to which combinatorial processes apply: While DMM assumes that only verbs taking productive/default affixes across the entire paradigm engage combinatorial processes, SAM argues for a wider application, proposing that all stem−affixes combinations are derived through combinatorial processes. These differences have direct implications, in German, for ABA past participle forms: Only under SAM are these verbs the outcome of combinatorial processes. The contrasting views the two theories hold about the processing of ABA past participle forms can be tested in several ways, including the analysis of the errors that individuals with acquired language impairment make with past participle forms—the approach we pursued in our investigation.

Issues concerning the representation and processing of regular and irregular inflections have been extensively investigated with neuropsychological patients with acquired language impairments (e.g., Cortese, Balota, Sergent-Marshall, Buckner, & Gold, 2006; Miozzo, 2003; Miozzo & Gordon, 2005; Patterson, Lambon-Ralph, Hodges, & McClelland, 2001; Penke, Janssen, & Krause, 1999; Tyler, Randall, & Marslen-Wilson, 2002; Ullman et al., 1997; Ullman & Gopnik, 1999). Many of these investigations have relied on the *elicitation task* as a fundamental experimental tool. Participants in this task are presented with a verb (e.g., *walk*) and are asked to produce another inflected form of this verb (e.g., *walked*) in order to complete a brief sentence. Studies conducted in different languages have demonstrated double dissociations with this task, with some patients having greater difficulty with irregular versus regular inflections (e.g., Cortese et al., 2006; de Diego Balanguer, Costa, Sebastián-Gallés, Juncadella, & Caramazza, 2004; Miozzo & Gordon, 2005; Patterson et al., 2001; Penke et al., 1999) and others exhibiting the opposite pattern (e.g., Tyler et al., 2002; Ullman et al., 1997; but see Bird, Lambon Ralph, Seidenberg, McClelland, & Patterson, 2003, for a discussion of whether these deficits reflect difficulties with inflection per se or can be accounted for by phonological or semantic impairment). These dissociations are readily explained within accounts proposing combinatorial processes for regular verbs and lexical encoding for irregular verbs (e.g., Marslen-Wilson & Tyler, 1997; Ullman et al., 1997) such that individuals who exhibit more severe problems with irregular verbs are assumed to be suffering from a lexical deficit with relative sparing of combinatorial mechanisms. The reverse pattern of selective difficulties with regular forms is accounted for by assuming a deficit affecting combinatorial mechanisms with relative sparing of lexical processing.

In this investigation we examined the performance of a native German speaker, with initials WRG, who suffered a stroke that produced severe difficulties in spoken language production. A primary component of WRG's language

[2] It is not necessary to assume inhibitory links in German since the activation received by the −en suffix from ABA verbs and stem-change verbs overrides the default activation reaching the −*t* suffix.

production impairment was a disruption to lexical retrieval processes. Our primary experimental tool was the elicitation task, which we used to prompt the various forms of German past participle verbs (AAA, ABA, ABB, ABC, and mixed). The results of the elicitation task were used to investigate differences in predictions derived from DMM and SAM.

As emphasized earlier, the two models diverge specifically with regard to their assumptions concerning the circumstances under which combinatorial processes of word formation apply: DMM restricts combinatorial processes to productive affixes and requires lexical processing for all other verb forms; SAM allows combinatorial processing for the full range of stems. The elicitation task applied in the case of an individual with a lexical retrieval deficit provides an opportunity to examine these contrasting assumptions. The participant is given the basic stem form of a verb—in our case by providing the verb in the present tense in the preamble portion of each trial (see examples in Table 2).

In individuals with lexical retrieval deficits, providing the basic stem serves two purposes. First, lexical retrieval demands are significantly reduced for this stem. As a result, one can more successfully isolate and observe the integrity of the combinatorial processes. Second, if combinatorial processes are reasonably intact, the task can (among other things) help to reveal which verb forms are generated from the combination of basic stems and affixes and which are not. Very simply: When an individual with a lexical deficit is provided with the basic stem, verbs that rely on combinatorial processes involving the basic stem are more likely to be produced correctly than those that do not. These characteristics of the elicitation task allow us to examine three specific predictions that involve response accuracy, frequency effects, and error types (see summary in Table 3).

Response accuracy

In the elicitation task, the presentation of the basic stem reduces lexical access demands for all verb forms that have the basic stem in the past participle form; this would be the case for AAA and ABA verbs. Under DMM this task should facilitate the production of AAA past participle forms and to a lesser extent the production of other types of past participle forms (ABA, ABB, ABC, and mixed verbs), all of which are more reliant on lexical processing. However, under SAM, the ABA verb stems should be facilitated in the same manner as the AAA stems, while only ABB, ABC, and mixed verbs should be facilitated less. Critically, *under these conditions, performance with the past participle of ABA verbs should pattern with AAA verbs and not with the other irregular, stem-changing past participles of the ABB, ABC, and mixed verbs.*

Frequency effects

A number of findings have demonstrated that performance with verbs shows sensitivity to stem frequency when stems are specifically accessed during production (e.g., Alegre & Gordon, 1999; Baayen, Dijkstra, & Schreuder, 1997). Stem frequency corresponds to the number of times in which a stem is

Table 2. *Examples of sentences presented in the elicitation task*

Verb category	*Eliciting sentence*	*Expected response*
AAA	Heute frage ich. Gestern habe ich _____. [Today I ask. Yesterday I have _____.]	(*gefragt*) [asked]
ABA	Heute rate ich. Gestern habe ich _____. [Today I guess. Yesterday I have _____.]	(*geraten*) [guessed]
Stem-change[a]	Heute werfe ich. Gestern habe ich _____ [Today I throw. Yesterday I have _____.]	(*geworfen*) [thrown]

[a]The verbs included in this group were ABB, ABC, and mixed verbs; their past participles required different stems from those of the present tense inflections shown as eliciting verbs.

Table 3. *Predictions for WRG's production of German past participles in the elicitation task*

	Prediction/Model	
Critical results	*Dual-mechanism model (DMM)*	*Stem-based assembly model (SAM)*
Response accuracy	AAA > ABA, ABB, ABC, and mixed verbs	AAA and ABA > ABB, ABC and mixed verbs
Frequency effects (ABA, ABB past participles)	Effects of surface frequency	Effects of stem frequency
Incorrect combinations of: • AAA stems + *en* • ABB and ABC past participle stems + *t*	These errors are unexpected	These errors can be observed

encountered in the various inflections of a verb—for example, the sum of the frequency of *frage* [(I) ask], *fragst* [(you) ask], and all the other inflections of the verb *fragen* [to ask] that contain the stem −*frag*. In the context of this investigation, therefore, SAM predicts that performance with the German past participle for all verb types should be sensitive to stem frequency. In contrast, the DMM predicts that only AAA verbs should exhibit sensitivity to stem frequency. It is generally assumed that sensitivity to surface frequency—that is, the number of occurrences of an individual inflected form—occurs when morphologically complex whole word forms are processed (Ford, Marslen-Wilson, & Davis, 2003; Schreuder & Baayen, 1997; Taft, 1979). Proponents of DMM explicitly predicted surface frequency effects when testing ABA, ABB, and ABC past participle formation with neurologically intact participants (Clahsen, Eisenbeiss, & Sonnenstuhl-Henning, 1997; see also Sonnenstuhl et al., 1999). On the same basis, one would assume that DMM would predict that an effect of surface frequency should also appear when ABA, ABB, and ABC are tested in individuals with lexical damage. In contrast, no surface frequency effects are expected for AAA verbs. SAM does not make predictions with regard to surface frequency, among other reasons because the possibility that suffix selection is subject to frequency is left underspecified in the model. In our investigation, the contrasting predictions concerning the effects of stem and surface frequencies were tested with ABA and ABB past participles (as only these, due to facts of word distribution in the language, allow a decoupling of stem and surface frequency). Specifically, *we examined whether the accuracy with which WRG produced ABA and ABB past participles was affected by stem frequency, as predicted by SAM, or by surface frequency, as expected by DMM.*

Error types

The two theories make different predictions with regard to the types of error that might be observed. According to SAM, the system may generate unattested forms resulting from the incorrect combinations of stems and affixes that engage the combinatorial process. Specifically, the following two types of error might be expected with German past participles: AAA stems + −*en* and ABB/ABC past participle stems + −*t*. Both of them are possible under SAM because the various stems and suffixes are available to the combinatorial mechanisms; as a result, any disruption of this process could determine the incorrect combinations of all of these elements. However, explaining these errors under DMM represents a challenge. The suffix −*en* is not encoded as a distinct entity and is, hence, not available for combination with AAA stems. Similarly, ABB and ABC stems are not available to the combinatorial process and, therefore, are unlikely to have the opportunity to combine with the affix −*t*.

An alternative account, based on analogy, can be proposed within the DMM framework. The details of such an account is discussed in a later section.

In summary, through a detailed examination of response accuracy and error types of an individual with acquired language production impairment, we are able to specifically evaluate the circumstances under which combinatorial and lexical mechanisms apply during the spoken production of morphologically complex forms.[3]

Case study

WRG was born in Germany, and German was his mother tongue. At the age of 8, he moved to China where he lived with his German-speaking family until the age of 18, attending an international, English-speaking high school. WRG then moved with his family to the US where he remained through the time of the investigation. WRG earned a college degree and a degree in law, and until his retirement he worked as a certified public accountant. While, as an adult, English was his dominant language (he spoke it daily at home and at work), he maintained his German fluency by regularly conversing with family and reading German books and periodicals. In July 2004, he suffered a stroke that involved the area of the distribution of the left middle and posterior cerebral arteries. The stroke resulted in damage primarily in the left frontal lobe but also extending in the left temporal and occipital lobes. Our investigation started two years after the stroke, when WRG was 76 years old, and continued for about a year. During this time WRG's condition remained stable. English and German were both affected. Here we report on WRG's deficit in German (for a description of his impairment in English, see Miozzo, Costa, Hernández, & Rapp, 2010), though we note that the pattern of impaired and spared performance was similar in both languages.

WRG's spontaneous speech was reduced to short utterances that were produced with considerable effort. Similarly, his spoken picture naming was errorful and effortful (15% accuracy; 19/123). Most of WRG's naming errors were neologisms that bore little resemblance with the target word (*Besen* [broom] → /sage/). He also produced a few perseverations, semantically related responses, and phonologically related responses (*Kerze* [candle] → /perz/). Further indication of the severity of WRG's lexical retrieval deficit was given by the weak effect of phoneme cueing: The first phoneme of a target word resulted in successful picture naming on only 44% (8/18) of trials on which it was provided. When spoken production difficulties are primarily due to a lexical retrieval failure, good repetition performance is expected (Goldrick & Rapp, 2007). With regard to the repetition of monomorphemic nouns, WRG was 100% correct (42/42). This excellent performance rules out significant postlexical sources of disruption to phonetic, articulatory, or motor processes.

WRG was able to accurately repeat short sentences (e.g., *Der Hund bellt* [the dog barks], *Die Kleine läuft schon* [the little one is already walking]; short sentences were 3–5 words long; 10/10 correct) but not long ones (5/10 correct; sentences were 5–10 words long, including embedded relative clauses; materials were from the Aachen Aphasia Test, AAT; Huber, Poeck, Weniger, & Wilmes, 1983).

A verbal short-term memory deficit is likely to have contributed to WRG's difficulties in repeating the long sentences as well as to his low score in the Token Test (9/40 correct with complex sentences).

[3] Penke et al. (1999) and Penke and Westermann (2006) examined the production of regular and irregular past participle forms in a group of German-speaking aphasics using the same elicitation task as the one that we used in our study. While most of the participants of the two studies (10/13) responded less accurately to irregular forms, 2 participants were equally impaired with both verb forms. Unfortunately, their results cannot help us to adjudicate between the contrasting predictions that DMM and SAM make about accuracy for ABA verbs, error types, and frequency effects. These limitations are due to the fact that ABA verbs were not tested specifically, and the critical errors for evaluating the models were not reported. Moreover, it is difficult to draw conclusions on the effect of surface frequency reported by Penke et al. (1999) given that a control of stem frequency, a variable typically correlated to surface frequency, was not included.

Access to single word meaning was largely intact as evidenced by his 95% accuracy on a word–picture matching task in which a target picture was shown along with a closely semantically related picture foil (19/20 correct).

In sum, on the basis of these findings, a lexical retrieval deficit is likely to be the primary source of disruption affecting WRG's spoken language production difficulties.

EXPERIMENT: PRODUCING THE GERMAN PAST PARTICIPLE

Method

Materials and procedures

In the elicitation task, target verbs were presented in the "preamble" in their (indicative) present tense, in either the first or the second person singular (see the examples in Table 2). Across all verb types, the present tense forms always used the basic stems and the suffix −*e* (first person singular) or −*st* (second person singular). As in prior studies (e.g., Miozzo, 2003; Ullman et al., 1997), the sentences were printed and were presented visually. In addition, sentences were also read out loud to WRG to ensure a correct input. WRG was asked to complete the sentences by orally producing only the past participle of the target verbs. Responses were digitally recorded. To avoid interference from English, testing sessions were carried out entirely in German by the first author (J.C.), a native German speaker.

Target verbs were of different types (AAA, ABA,[4] ABB, ABC, and mixed) and always took the *ge*− prefix. We refer to ABB, ABC, and mixed verbs as *stem-change verbs*, since the stems of their past participles differed from the stems of the indicative forms presented in the elicitation task (see examples in Table 2). WRG produced 1,280 past participle forms that came from four different lists.

1. List 1 was used for comparing accuracy across AAA, ABA, and stem-change verbs. The relatively small number of ABA verbs existing in German ($N = 41$) constrained the construction of List 1. To test a sizeable number of ABA verbs while keeping identical criteria across verb types, we selected 42 AAA verbs, 25 ABA verbs, and 26 stem-change verbs and presented them between 3 and 5 times ($N =$ total verb presentations per category: AAA = 165, ABA = 119, stem-change = 106; across all verb types verbs were presented on average four times). For List 1, the AAA, ABA, and stem-change verbs were matched for the following features: number of stem phonemes, stem frequency, and surface frequency (ps $>$ .05; frequency values from CELEX; Baayen, Piepenbrock, & Van Rijn, 1993; see means in Table 4). Compared to the other types of verb, AAA verbs had significantly fewer *total* phonemes ($p < .001$), a discrepancy explained by the shorter suffix taken by the AAA verbs (−*t* instead of −*en*).
2. Lists 2 and 3 were used to test the contrasting predictions that the different models make regarding the effect of frequency on performance accuracy. The critical predictions can be tested in the past participle only with ABA and ABB verbs because, given the frequency distribution of the language, these are the only past participle forms in which stem and surface frequencies can be uncoupled. List 2 consisted of two sets of 18 past participle forms (10 ABA verbs, 8 ABB verbs), each presented three times, for a total of 54 verbs per set. The verbs of List 2 differed in stem frequency (high vs. low), $t(106) = 7.06$, $p <$ .001 (see Table 5 for frequency means and ranges) but were matched for surface frequency and number of phonemes (p values$>$.05). List 3 included two sets of 14 verbs (8 ABA verbs, 6 ABB verbs) repeated three times (42 verbs

[4] Some ABA verbs can take different stems in the (indicative) present tense (e.g., ich *laufe* [I run], first person singular vs. du *läufst* [you run], second person singular) and past participle (*gelaufen*, [run]). These ABA verbs were not used to elicit the responses we analysed here (but they were used in a task described in Footnote 5).

Table 4. *Characteristics of the German past participles used in the elicitation task*

		Mean frequency[a]		Mean phoneme number	
Verb type	*N*	*Stem*	*Surface*	*Stem*	*Word*
AAA	165	85	19	4.1	7.1
ABA	119	81	19	4.1	8.1
Stem-change[b]	106	72	25	4.2	4.2

[a]Frequency counts (per one million words) from CELEX (Baayen et al., 1993). [b]This group of verbs included ABB, ABC, and mixed verbs; they took different stems in the past participle and in the indicative forms shown in the elicitation task.

Table 5. *Stimulus characteristics and accuracy in the elicitation task for sets of German past participles that contrasted in stem or surface frequency*

				Stem frequency[a]		Surface frequency[a]			Correct responses	
Verb set			*N*	*M*	*Range*	*M*	*Range*	*Mean length (N phonemes)*	*N*	*%*
List 2 (stem-frequency varied)	Stem frequency	High	54	107	41–344	12	1–33	8.1	25	46
		Low	54	23	7–40	10	2–23	8.1	14	26
List 3 (surface-frequency varied)	Surface frequency	High	42	149	31–326	50	22–110	8.3	22	52
		Low	42	110	29–344	10	1–18	8.0	18	43

[a]Frequency counts (per one million words) from CELEX (Baayen et al., 1993).

per set). Verbs in List 3 differed in surface frequency (high vs. low), $t(82) = 10.71$, $p < .001$, but were matched for stem frequency and number of phonemes (ps $> .05$; see Table 5 for frequency means and ranges). ABA and ABB verbs were equally represented within each of the two sets of Lists 2 and 3.

3. List 4 included 454 AAA verbs and 340 stem-change verbs. It was created to collect additional errors from WRG and obtain the same token frequency distribution of –*t* and –*en* suffixes existing among German past participles (Clahsen, 1999). Within Lists 1–4 combined, –*t* suffixes and –*en* suffixes occurred 48% and 52%, respectively.

The items from the four lists were presented together in random order, and the testing took place over several sessions of approximately one hour in length. Verbs were never repeated in the same testing session. Practice trials were provided in each session to (re)familiarize WRG with the task. We analysed the first complete response produced by WRG on each trial.

Results

Three aspects of WRG's responses from the elicitation task should be highlighted. First, WRG invariably produced the prefix *ge*–. This result is not surprising given that the prefixed *ge*– was required by all of the tested verbs. Second, WRG did not produce semantically related errors. Third, we observed errors like *gesagt* [said] → /gesagət/ or /gesagte/ in which there was the insertion of additional phonemes (typically a schwa). These errors were observed only when WRG produced past participles of the AAA type and almost exclusively when suffix addition led to obstruent–obstruent consonant clusters (as /gt/ in *gesagt*; see Goldberg, Cholin, Bertz, Rapp, & Miozzo, 2007, for a discussion of these responses).

These errors were ignored here because they were likely to involve phonological processes that are subsequent to the stem and suffix selection processes that are of interest in the present investigation; moreover, this type of error would not affect a scoring that considers whether the correct stems and suffixes were retrieved.

The reminder of this section is organized according to the predictions listed in Table 3 that serve to differentiate the two theories under consideration.

Response accuracy across verb types

It is only for the ABA verbs that the two models make contrasting predictions about WRG's responses in the elicitation task. Specifically, SAM predicts: (a) relatively high and similar accuracy for ABA and AAA verbs and (b) lower accuracy for stem-change verbs. DMM, on the other hand, predicts: (a) relatively high accuracy for AAA verbs and (b) lower accuracy for ABA and stem-change verbs.

Table 6 shows the accuracy with which WRG produced the stem and the suffix in past participle responses to AAA, ABA, and the stem-change verbs. WRG's responses were 58% (96/165) correct with AAA verbs and significantly lower for stem-change verbs (26%, 28/106; stem-change verbs vs. AAA verbs), $\chi^2(1) = 26.24$, $p < .001$. WRG's responses to ABA verbs are critical: These forms were 65% (78/119) correct. Thus, ABA verbs were identical in accuracy to AAA verbs, $\chi^2(1) = 1.58$, *ns*, but they differed markedly from stem-change verbs ($\chi^2 = 34.45$, $p < .001$). We further explored whether this result could be due to differences in the number of presentations of the individual verbs (see Method section). Presentation numbers were entered in a regression analysis as predictor of WRG's response accuracy (along with phoneme lengths, surface frequencies, and stem frequencies). Results revealed no significant effect of presentation numbers ($t < 1$). The critical finding is that ABA verbs pattern with AAA verbs.

Table 6. *WRG's accuracy with different types of German past participles in the elicitation task*

Verb type	*N*	*Complete responses (%)*	*Stems (%)*	*Suffixes (%)*
AAA	165	58	78	66
ABA	119	65	84	74
Stem-change[a]	106	26	32	60

[a]This group of verbs included ABB, ABC, and mixed verbs; they took different stems in the past participle and in the indicative forms shown in the elicitation task.

These results are consistent with SAM but unexpected under DMM. The predictions of each account hold not only for the accuracy of the entire responses but also for the accuracy with which WRG produced the stems. WRG's erroneous responses typically departed only minimally from the targets, so that we were able to reliably isolate the morphological constituents of WRG's responses. Table 6 shows WRG's correct response rates for the stems. Once again, the lowest accuracy rates were observed with stem-change verbs (34/106, 32%; in all comparisons with AAA and ABA verbs, χ^2s had ps $< .001$), and stem accuracy was similar for AAA verbs and ABA verbs (130/165, 78% vs. 100/119, 84%; $\chi^2 = 1.23$, *ns*).

These results clearly indicate that WRG's responses were the most accurate with AAA and ABA verbs and significantly less accurate with the other stem-change forms. These results would be uninteresting if this difference were simply the result of a response strategy according to which WRG generally responded to all forms by inflecting the basic stem he was given in the preamble of each elicitation trial. If that were the case, then accuracy would be higher for ABA and AAA than for stem-change forms, but would not reflect lexical retrieval processes. However, under that scenario, we would expect basic stems to appear in similar proportions in WRG's responses to AAA verbs and ABA verbs as well as in stem-change verbs. Contrary to this, the results indicate that basic stems were far more likely to be (correctly) produced with AAA and ABA verbs (230/284, 81%) than to be (incorrectly) included in the responses to stem-change verbs (48/106, 45%), $\chi^2(1) = 48.06$, $p < .001$.[5] This does not support the possibility that WRG's responses were simply attempts to combine the basic stems presented in the elicitation prompt with a suffix.

Frequency effects

Given their differences regarding which verb forms should be represented in a decomposed fashion, DMM and SAM also differ with regard to their predictions about the effects of frequency on production accuracy. By assuming that all of the German verbs are processed in a decomposed fashion, SAM predicts a pervasive effect of stem frequency across all verb types. In contrast, proponents of DMM anticipate a significant effect of stem frequency only for AAA past participles (Clahsen et al., 2001; Clahsen et al., 1997). Instead, under DMM, all other verb forms (ABA, ABB, and ABC), are predicted to show effects of surface frequency. These contrasting predictions were tested by using ABA and ABB verbs and selectively varying stem frequency (List 2) or surface frequency (List 3). Stem frequency effects are expected under SAM, whereas surface frequency effects are predicted by DMM.

The results (see Table 5) indicate that WRG's performance was significantly sensitive to stem frequency (high stem-frequency verbs = 46% correct, 25/54; low stem-frequency verbs = 26% correct, 14/54, $\chi^2 = 4.85$, $p = .02$). However, differences in surface frequency did not significantly affect WRG's accuracy (high surface-frequency verbs = 52%, 22/42; low surface-frequency verbs = 43%, 18/42; $\chi^2 < 1$). This pattern of results corresponds to the predictions of SAM.

Error analyses

The types and distribution of WRG's errors across the various kinds of German verbs represent another area where DMM and SAM make different predictions. The two types of error reported on below provide two critical test cases for adjudicating between the two accounts. In each case, the issue is whether stems combine with incorrect suffixes. The logic is that incorrect stem–suffix combinations can arise if both stems and suffixes are available to the combinatorial mechanisms. DMM assumes that they are not, while SAM assumes that they are. The results show that WRG frequently produced incorrect stem–suffix combinations, thus aligning with SAM. At the end of this section, we discuss two accounts that might be considered to attempt to explain WRG's errors under DMM. We argue that neither of these accounts, however, provides a satisfactory explanation.

To examine the largest possible error pool, we analysed errors collected from all four lists (1,280 responses).

Test Case 1: AAA verbs. The suffix *–en* appears in the German past participle only with ABA, ABB, and ABC verbs. Therefore, appending the suffix *–en* to an AAA stem (*frag*) creates an illegal combination (**gefragen*; the expected response is *gefragt*). Because DMM assumes that the suffix *–en* is not visible to the combinatorial processing responsible for assembling the past participles, the suffix *–en* should not be appended to AAA stems. However, SAM assumes that because the suffix *–en* participates in combinatorial processing, this suffix can be incorrectly appended to AAA stems.

Table 7 shows the incidence of incorrect suffixes with the various categories of German verbs. The suffix *–en* accounted for a sizeable proportion of the errors observed with AAA verbs (63/122, 52%). This result is inconsistent with DMM, which predicts that such responses should not occur.

[5] Similar percentages were found when we examined the entire corpus of 1,280 responses (75% vs. 35%), $\chi^2(1) = 216.11$, $p < .001$. Another argument against this interpretation comes from an elicitation task in which the prompts were second person singular ABA verbs that do not bear the infinitive stem. An example is *trittst* [(you) kick]; its stem *tritt–* differs from the infinitive stem *tret–*. In this task, WRG only reused the form given in the prompt in 3/29 times (10%), indicating that prompt use was not a common response for WRG.

Table 7. *Error distributions for WRG's past participle errors in which correct stems combined with incorrect suffixes*

	Incorrect suffix												
	− *t*		− *en*		− *ten*		− *e*		*No suffix*[b]		*Other*[c]		
Verb class	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*	*Total*[a]
AAA	n.a.		63	52	16	13	31	25	9	7	3	2	122
ABB + ABC (stem change)	24	77	n.a.		1	3	2	6	4	13	0	0	31

[a]Suffix errors produced in the whole corpus of 1,294 responses. [b]Zero suffixation is rare in German verb inflection, occurring only in the imperative. [c]The "other" responses included the pseudosuffix −*es* and the suffix −*est*.

Test Case 2: ABB and ABC verbs. A second test case involves errors like *geworfen* → "geworft", where the correct, irregular past participle stem *worf* appears with the incorrect suffix −*t*. According to the DMM, errors in which the past participle stem of an ABB and ABC verb is correctly produced but affixed with −*t* should not occur. If, as claimed by this model, *geworfen* [thrown] is stored as a full word in the lexicon, then the stem *worf* is not available to serve as input to the combinatorial processing. However, such combinations are not disallowed by SAM. Because SAM posits that the past participle stems of ABB and ABC verbs are retrieved from the lexicon and are entered into combinatorial processes, these stems are then available to be combined with incorrect suffixes in conditions of language impairment. We identified 31 errors in which the past participle stems of ABB and ABC verbs were correctly produced and incorrectly affixed. Among these, the suffix −*t* was produced 24/31 times (77%). Thus, far from being rare, the suffix −*t* was found frequently among the errors involving ABB and ABC verbs.

A possible account of WRG's errors under DMM. DMM could explain the illegal combination of stems and affixes if one assumed that they occur as a result of confusions of verb forms, as when the present form is produced instead of the past participle form. One might imagine that an incorrect encoding of syntactic or semantic features could lead to this kind of form substitution. However, 0/122 AAA stem + *en* combinations and only 2/31 ABB/ABC past participle stem + *t* combinations corresponded to other verb forms. Thus, an explanation of WRG's errors in terms of confusions between verb forms is not tenable.

A second avenue one might pursue in attempting to account for WRG's errors under DMM is the "analogy account". Clahsen (1997) found that neurologically intact German speakers typically used the regular suffix −*t* to inflect nonwords introduced. However, nonwords rhyming with existing stem-change verbs represented an exception; here, the suffix −*en* was overwhelmingly preferred. To explain this deviating pattern, Clahsen (1997) hypothesized that these nonwords[6] activated the lexical nodes of existing stem-change verbs, which, in turn, provided a model for producing the suffix −*en*. If the lexical entries of stem-change verbs were not sufficiently activated, the default suffix −*t* was selected.

To attempt to extend this type of account to WRG's errors one would have to assume that the suffix −*en* was attached to AAA verbs that rhyme with/sound like stem-change verbs and that the suffix −*t* was attached to stem-change verbs that rhyme with/sound like AAA verbs. Furthermore, the analogical mechanisms would have to be able to apply very specifically—only to suffixes, not to stems—in order to explain

[6] It should be noted that these results were obtained with nonwords. It is presently unclear whether similar effects of analogy will be observed with the inflections of real words.

WRG's errors where the suffixes were selectively substituted while the stems were left intact. This would be particularly challenging for the stem-change verbs, for which WRG successfully achieved the phonological changes in the stem but produced the incorrect affix. These various considerations suggest that an analogy-based account is not only ad hoc but also incapable of providing a parsimonious explanation of WRG's errors. This does not, of course, preclude that such mechanisms could provide a valid explanation for the pattern of nonword inflection performance reported with neurologically intact German speakers.

GENERAL DISCUSSION

The two proposals

The two proposals we have evaluated—the dual-mechanism model and the stem-based assembly model—make different claims regarding the processing of inflected words. Their differences primarily involve contrasting views about the role of affix productivity in determining the conditions under which combinatorial processes apply. While DMM holds that only verbs that take productive/default affixes *across their entire paradigm* engage combinatorial processes, SAM proposes that all stem–suffix combinations can be assembled through combinatorial processes. These different positions make different predictions regarding the representation and processing of the morphologically complex verbs in a language like German with multiple types of stem–suffix combinations, only one of which is considered to be productive. A unique opportunity to test these diverging views was offered by the investigation of the performance of a German-speaking, brain-damaged individual exhibiting an acquired language impairment affecting his lexical access abilities, while leaving fairly intact his combinatorial processing capacities. We used an elicitation task to evaluate this individual's ability to produce German past participles. In this way, we were able to test contrasting predictions made by the two models. We found that results concerning accuracy, frequency effects, and error types consistently favoured SAM.

The critical findings, briefly summarized, are as follows:

1. The two theories differ with regard to whether or not they assume that stems are separately represented for all verbs, or only for those that take productive affixes across their paradigm. For an individual such as WRG with a lexical retrieval deficit, verbs with explicitly represented stems would be expected to benefit from an elicitation task that reduces lexical retrieval demands by providing the participant with the basic stem form (see Table 3). Under those circumstances, SAM and DMM make different predictions specifically regarding the production of ABA verbs in the past participle. DMM predicts that because the basic stem is not represented in the past participle form of ABA verbs, WRG's accuracy with these verbs should pattern with that of other stem-change, irregular verbs. In contrast, SAM predicts that because the basic stem is represented for ABA verbs, WRG's performance with these verbs should benefit from the elicitation paradigm, and his accuracy with these verb forms should pattern with that of the regular AAA verbs. The results clearly supported the predictions of SAM.
2. DMM predicts differential effects of surface and stem frequency depending on whether or not a verb takes productive affixes (Clahsen et al., 2001; Clahsen et al., 1997). Specifically, performance with verbs that take the productive affix should be sensitive to stem frequency while all others should be sensitive to surface frequency but not stem frequency. In contrast, SAM predicts sensitivity to (at least) stem frequency for all verb types. ABA and ABB verbs are particularly well suited to test these alternative predictions, since stem and surface frequency can be dissociated with these verbs. Contrary to the predictions of DMM, we did not observe significant

effects of surface frequency. However, consistent with the expectations of SAM, we found significant effects of stem frequency.

3. The two theories differ with regard to the availability of stems and affixes to the combinatorial word formation processes. According to DMM, only productive affixes and those stems of verbs that use these affixes are available. According to SAM, however, all stems and affixes are available. We observed errors involving stem + affix combinations that would be predicted by SAM to occur if there were occasional failures of the combinatorial process. These same errors are difficult to reconcile with DMM as these particular morphemes should not be available to be (mis)combined in errors. Moreover, we examined various arguments that one might want to develop to explain such errors under DMM but found that they were not tenable.

Having reviewed the evidence favouring the claim that all German inflected verbs are subject to assembly, we would like to point out that we remain neutral with respect to the question of whether or not inflected verbs can also be represented and processed as whole words. A few models of word comprehension propose that frequently used multimorphemic words are represented both as whole words and in a decomposed form (Anshen & Aronoff, 1988; Baayen et al., 1997; Caramazza, Laudanna, & Romani, 1988; Frauenfelder & Schreuder, 1992). This possibility is not incompatible with SAM, which, while proposing that compositional processing applies to all inflections, does not rule out that additional, whole-word representations may exist in certain cases. However, it is worth noting that, in contrast to models of word comprehension, current models of word production do not assume that inflected words are represented as whole words, instead proposing only compositional processes (Dell, 1986; Levelt et al., 1999).

Psycholinguistic evidence and SAM

Questions regarding the representations and processes involved in producing German verb inflections have been investigated in several psycholinguistic studies with neurologically intact speakers (see Clahsen, 1999, for an overview). The results of these studies, which are reviewed in this section, either confirm key predictions of SAM or find reasonable accounts within the framework of the model.

SAM makes clear predictions about the priming effects one should observe in German with pairs of stem-related, visually presented words such as *gekauft* [bought]–*kaufen* [to buy]. If we extend the core assumption of SAM that all German verbs are subject to combinatorial processing to visual word recognition, comparable priming effects can appear for AAA verbs and stem-change verbs. This was the result obtained by Smolka, Zwitserlood, and Rösler (2007) with real and novel verbs in a visual lexical decision task. It should be noted, however, that in a prior experiment Sonnenstuhl et al. (1999) found stem priming for AAA verbs but not for ABA verbs. However, the findings of Sonnenstuhl et al. should be interpreted cautiously. As argued by Smolka et al., the finding of a stem priming effect restricted to AAA verbs could have resulted from imbalances concerning the surface frequencies of the tested verbs. When materials were accurately matched for frequency by Smolka et al., a stem priming effect was found for all verb types.

As we have seen above, another key prediction of SAM concerns the type of frequency effect expected with stem-change verbs. Because stem-change verbs are assumed to undergo assembly in production and decomposition in comprehension, their processing should be sensitive to stem frequency. Results obtained by Clahsen et al. (2001) with stem-change (past tense) verbs confirmed this prediction. Responses in a lexical decision task were faster for high than for low stem frequency preterite forms of irregular verbs (ABA, ABB, ABC) that were matched for surface frequencies. Against the background of these findings, the authors argued that irregular preterite stems engage in a combinatorial processing of stem + affix but that stems of irregular past participle do not (see also Clahsen et al., 1997; as well as Sonnenstuhl et al., 1999). SAM predicts their findings with regard to preterite stems and extends the prediction to past participle stems. The results of our investigation reveal that combinatorial processes are more broadly available—that is, include past participle formation for stem-change verbs.

A final result that deserves attention was obtained with novel verbs by Clahsen et al. (1997). German-speaking participants learned novel verbs that were introduced either as "regular" verbs keeping the same stem in the infinitive and past tense (*pniewen–pniewte*), or as "irregular" verbs undergoing stem change between the two tenses (*plohmen–pliem*). Later, participants performed a same/different decision task on the past participle forms of those novel verbs—for example, they decided whether *gepniewen–gepniewen* were identical. Each novel verb was shown with the "regular" suffix –*t* and the "irregular" suffix –*en*. Previous findings with the same/different decision task indicate that grammatical and morphological violations slow down responses (Forster, 1987; Forster & Stevenson, 1987). Response latencies differed between "regular" and "irregular" novel verbs. Specifically, while responses to "regular" novel verbs were significantly faster with the "regular" suffix –*t* than the "irregular" suffix –*en*, the two suffixes yielded responses of comparable speed to that for "irregular" novel verbs. These results can be explained assuming the default application of the suffix –*t*, as proposed under SAM. "Regular" verbs bearing the "irregular" suffix –*en* run counter to the expectation that "regular" and novel verbs should carry the "regular", default suffix –*t*. On the other hand, the two suffixes are both unexpected with "irregular" verbs: the suffix –*t* because it is "regular", the suffix –*en* because it is not the default choice with novel verbs. This provides a possible account for the equivalence of response latencies for these two forms with "irregular" novel verbs.

The range of findings that can be accounted for by SAM makes it a compelling hypothesis. To be sure, a number of details concerning morphological processing and lexical access more generally need to be specified in SAM. Nonetheless, the convergence of evidence from both neuropsychology and psycholinguistics provides a strong foundation for the further development of SAM.

An alternative view: A subsymbolic distributed approach

DMM and SAM share with other theories (e.g., Marslen-Wilson & Tyler, 1997; Pinker & Ullman, 2002; see also Berent, Pinker, & Shimron, 1999) a dual-mechanism approach to inflection, according to which qualitatively different mechanisms (combinatorial vs. lexical look-up) underlie the cognitive (and brain) processing of regular and irregular inflections, respectively. A prominent alternative has involved various types of connectionist models of word production (Elman et al., 1996; Joanisse & Seidenberg, 1999; MacWhinney & Leinbach, 1991; Mirkovic, MacDonald, & Seidenberg, 2005; Plunkett & Marchman, 1993; Rumelhart & McClelland, 1986; Seidenberg & Gonnerman, 2000). The common element across these models is the claim that the distinction between lexical look-up and combinatorial processing shared by other proposals is unnecessary and that, instead, word generation can be accomplished through the association of word sounds and word meanings. Within this approach, morphological structure corresponds to statistical regularities in the complex pattern of sound–meaning association strengths. In distributed, subsymbolic representational systems such as these, the frequency and consistency with which information is encountered determine how information is represented in the language production networks.

Joanisse and Seidenberg (1999) proposed a connectionist network for the production of regular and irregular English past tense. This network is of particular relevance here as it was claimed to simulate the neuropsychological deficits selectively affecting the processing of regular and irregular inflections that have been documented with English-speaking patients. Crucially, these successful simulations were obtained with a network that did not include mechanisms specifically devoted to word morphology. Dissociations between regular and irregular inflections were possible, nonetheless, because different types of representations and connections were differentially involved in the processing of regular versus irregular verb inflections.

The network included three distinct types of representations—semantic features for encoding word meaning and two sets of phonological features, for comprehension and production, respectively. The network could simulate different tasks, including the elicitation task. During the learning phase of network development when the connection weights were being established, the exposure to regular, stem + *ed* inflected verbs led to the formation of strong connections between the "comprehension" phonemes comprising the word stems and the "production" phonemes /t/ and /d/ marking the past tense. In addition, during this stage, connections were established between the semantic and phonological units that were critical for producing irregular verb inflections. These allowed the network to override the regular /t/−/d/ default pattern and instead respond with the idiosyncratic forms required by irregular verbs.

Simulations that selectively disrupted the semantic and phonological components revealed that regular verbs were particularly affected by damaging phonological processing, while irregular verbs were more severely affected by perturbing the semantic processing. Based on these results, selective deficits for regular inflections were accounted for by Joanisse and Seidenberg (1999) in terms of a phonological impairment, whereas selective deficits for irregular inflections were attributed to a semantic impairment. It was not necessary to appeal to mechanisms specifically devoted to lexical look-up and morphological assembly to account for the selective nature of the deficits affecting regular and irregular inflections.

However, the neuropsychological data relevant for evaluating the predictions generated by this account have come primarily from English and have been mixed. Consistent with the simulation data, the co-occurrence of semantic deficits and impairments for irregular verb inflections has been reported in semantic dementia (Patterson et al., 2001), a deficit primarily (but not exclusively) affecting semantic processing. The finding that phonological deficits are sometimes associated with marked difficulties with regular verb inflections are also in line with this account (Bird et al., 2003). However, evidence clearly inconsistent with Joanisse and Seidenberg's (1999) account includes the finding that irregular verb inflections were intact in a patient with semantic deficit (Miozzo & Gordon, 2005) and that irregular verb inflections were impaired in an individual with a phonological deficit (Miozzo, 2003). Moreover, Tyler et al. (2002) showed that deficits for regular inflections are not correlated with the severity of phonological impairments.

WRG's performance pattern may be added to the set of neuropsychological results that are problematic for the account advanced by Joanisse and Seidenberg (1999) since WRG's severe difficulties with irregular inflections were not associated with a frank semantic deficit but instead with difficulties in lexical retrieval. Alternatively, one might attempt to explain WRG's problems with verb inflections as caused by a phonological deficit. The results of Bird et al. (2003) suggest that the phonological complexity of English inflected words causes aphasic individuals with phonological deficits to fail specifically with these words. There are a number of reasons that make this unlikely in WRG's case. Prominent among them is his excellent repetition performance, which makes a primary phonological deficit unlikely. Furthermore, this type of account does not explain the production of responses in which the incorrect suffix is attached to the correct stem.

The role of productivity

Like other investigators, we have also directed our attention to German past participles for the purposes of understanding the role of productivity in inflectional morphology. The AAA past participle suffix is used productively as the default form, as is indicated by its use in borrowings and novel verbs. However, the results we obtained from WRG suggest that this productivity is not the critical factor in determining whether word inflections are derived by combinatorial mechanisms and are stored in a decomposed fashion (see also, as reviewed above, Smolka et al., 2007).

This may, at least in part, be due to the fact that productivity is not easily defined or identified. It may not be a coincidence that in many languages, including English and German, productive verb inflections are obtained by the combination of a basic stem and a suffix—this solution may have some clear design advantages.[7] However, morphological features of this sort are unlikely to be the only factors determining which inflection would ultimately emerge as the productive one. In both English and German, the high type-frequency with which certain verb inflections are used in the language has most certainly been a critical element for establishing the productivity of such forms. But frequency may not play the same critical role in other cases. The plural of German nouns provides a well-known example. German nouns take one of five suffixes in their plural forms: *−(e)n*, *−s*, *−e*, *−er*, and zero suffixes (stem change also occurs with the last three suffixes). Despite being the least frequent, the suffix *−s* is the default—productive—case, as attested by its appearance in borrowings and proper names, and is the preferential choice with nonwords in experimental settings (Marcus et al., 1995). The default status acquired by the suffix *−s* may also depend on its relative unmarkedness, as suggested by Janda (1990) and Stemberger (1999). That is, *−s* is not subject to the same constraints—both morphological (e.g., grammatical gender) and phonological (syllable number and structure, rhyming pattern)—that limit the use of the other suffixes. The suffix *−s* can thus be applied as the *Notpluralendung* (emergency plural ending), as van Dam (1940) aptly defined its role. An even more complex case is represented by denominal verbs—that is, verbs derived from preexisting nouns. In English, for example, denominal verbs are preferentially inflected as regular (stem + ed) forms, as in the example *the hammer*, *to hammer*, *hammered*. Linguistic and psycholinguistic evidence suggests that both semantic and syntactic factors are involved in the widespread regularization observed with denominal verbs (Bandi-Rao & Murphy, 2007; Gordon & Miozzo, 2008; Kim et al., 1991; Ramscar, 2002). Although a list of the factors implicated in productivity is most certainly incomplete at present, the emerging picture seems sufficiently clear to draw the generalization that such factors vary not only cross-linguistically but also across the morphological forms present in individual languages. That is, various case-specific factors conspire in determining the form that wins in each particular case. Of course, an important challenge for language scientists is to characterize the factors underpinning productivity in all individual instances. But an even greater (though more exciting) challenge is to determine whether the different factors co-occur with systematic regularity and whether any ranking exists, such that certain factors are more influential than others.

CONCLUSIONS

The question we set out to address with this investigation concerned the conditions under which combinatorial affixation processes apply. We contrasted two proposals that provided different answers to this question. On the one hand, the DMM proposes that combinatorial affixation applies only to "regular" verbs that take a productive affix and whose stems do not undergo change; on the other hand, SAM proposes that combinatorial affixation is available to all identifiable stems and affixes. In German, productivity and stem change can be decoupled given that there are verb forms that do not take the productive affix but also do not undergo stem change. Through a detailed study of the performance of a German-speaking aphasic individual we tested the different predictions generated from

[7] But it is worth pointing out that linguists have also described productive forms that do not involve stem + affix combinations, though these combinations exist in the language. Examples include the subtractive process observed with the nominative nouns in Lardil and the perfect verbs in Papago, and the incomplete phase in Rotuman (see Blevins, 1999, for a discussion of these cases).

these proposals, regarding accuracy, errors, and the effects of frequency. The results clearly reveal that combinatorial processing is not restricted to forms that take productive inflections but that, instead, these processes apply far more broadly to identifiable stems and suffixes. Essentially, these findings support a decoupling of productivity from compositionality such that combinatorial mechanisms apply as broadly as possible.

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