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Morphological priming in the German mental lexicon

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Abstract

We present results from cross-modal priming experiments on German participles and noun plurals. The experiments produced parallel results for both inflectional systems. Regular inflection exhibits full priming whereas irregularly inflected word forms show only partial priming: after hearing regularly inflected words (-t participles and -s plurals), lexical decision times on morphologically related word forms (presented visually) were similar to reaction times for a base-line condition in which prime and target were identical, but significantly shorter than in a control condition where prime and target were unrelated. In contrast, prior presentation of irregular words (-n participles and -er plurals) led to significantly longer response times on morphologically related word forms than the prior presentation of the target itself. Hence, there are clear priming differences between regularly and irregularly inflected German words. We compare the findings on German with experimental results on regular and irregular inflection in English and Italian, and discuss theoretical implications for single versus dual-mechanism models of inflection.

Keywords: Mental lexicon; Morphological priming; German inflection

1. Introduction

Much work in linguistics and linguistic theory has argued that languages have a

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dual structure and consist of two separate components, a lexicon of stored entries and a computational system of combinatorial operations to form larger linguistic expressions. In Chomsky's (1995) framework, for example, the computational component is conceived of as a finite set of operations which take lexical entries as inputs and form words, phrases and sentences. Computational operations manipulate abstract symbolic categories such as V and N rather than sounds or meanings directly. By contrast, the lexicon is conceived of as a finite list specifying category membership ('N(oun)', 'V(erb)', etc.) for each entry and idiosyncratic information regarding form and meaning. We argue that the distinction between the lexical and the computational system helps to explain priming differences between regular and irregular inflection.

Inflectional phenomena have been said to incorporate lexically based processes and computational operations into fairly discrete subsystems of language, such as the English past tense; see the distinction between 'words' and 'rules' in Pinker and Prince (1994) and Pinker (1999) and related linguistic work (e.g. Jackendoff, 1997). Two qualitatively different representations of inflected word forms are distinguished here: (i) full-form representations of inflected word forms stored in the lexicon and (ii) decomposed representations resulting from concatenating stems and affixes (= affixation). Affixation typically applies to regular inflection as in the past tense -ed, e.g. walked, which can be easily decomposed into stem + affix and readily extends to novel items, whereas lexically based inflection, on the other hand, epitomizes the irregular aspects of inflectional morphology including sublevel regularities as, for example, in irregular past tense forms (sing–sang, ring–rang, etc.).

Parallel distinctions may be found in the processes involved in the real-time production and comprehension of language such that regularly inflected words are processed differently from irregularly inflected ones, the latter by accessing full-form entries stored in memory and the former by a computational process that decomposes complex words into stems and affixes.

Current processing models of morphology, however, provide conflicting answers to the question to what extent the recognition of inflected words involves decomposition processes and to what extent it involves accessing stored word forms. Some researchers (e.g. Manelis & Tharp 1977; Butterworth, 1983; Feldman & Fowler, 1987) have developed single-mechanism models of inflection according to which all inflected word forms are listed and morphological decomposition plays no role at all. Connectionist models are similar in spirit and claim that morphological structure is not explicitly represented in the mental lexicon; rather, morphologically complex words are said to be represented like simple words, through associatively linked orthographic, phonological and semantic codes in terms of activation patterns over units and weighted connections between them (Rumelhart & McClelland, 1986; Seidenberg & McClelland, 1989; Elman, Bates, Johnson, Karmiloff-Smith, Parisi & Plunkett, 1996; Sereno & Jongman, 1997, among others). Other researchers have combined whole-word based representations with morphological decomposition in so-called dual-mechanism models (Laudanna & Burani 1985, 1995; Pinker & Prince, 1994; Frauenfelder & Schreuder, 1992; Chialant & Caramazza, 1995; Schreuder & Baayen, 1995; Clahsen, Marcus, Bartke & Wiese, 1996; Pinker, 1999).

One possibility of experimentally investigating morphological decomposition effects during the recognition of inflected words is via priming tasks in which the semantic, phonological and/or morphological relations between pairs of words are manipulated. Priming effects (manifested e.g. in shorter lexical decision times when compared with a baseline condition) have been found in several studies investigating the English past tense (see Stanners, Neiser, Hernon & Hall, 1979; Marslen-Wilson, Hare & Older, 1993, among others), but, as will become clear from the next section, the picture we get from these studies is not fully conclusive, due to a number of confounding factors.

The present study examines morphological decomposition effects by investigating two inflectional systems of German, past participle and noun plural formation. Results from three cross-modal priming experiments are presented and compared with related findings on other languages. The results are discussed with respect to the controversy between single and dual-mechanism models of inflection.

2. Morphological priming: results from previous studies

One morphological phenomenon that has received a lot of attention in the priming literature is the English past tense. Let us briefly summarize the main findings.

In their seminal paper, Stanners et al. (1979) found that the lexical decision times to the second of a pair of identical words (e.g. walk followed by walk) were faster than to the first. Thus, repeating a word is presumed to facilitate access to its lexical entry. Surprisingly, Stanners et al. also observed an equivalent amount of facilitation when the first word was a regularly inflected past tense form (walked) and the second word its stem (walk). In other words, a word stem and its regularly inflected past tense form were equally effective primes for lexical decision on the stem. Irregular past tense forms on the other hand produced less priming of the stem than did the stem itself, e.g. sing was primed to a much lesser extent by sang than by sing. All subsequent experiments have confirmed Stanners et al.'s finding of full priming for regularly inflected words (Kempley & Morton, 1982; Fowler, Napps & Feldman, 1985; Napps, 1989; Marslen-Wilson et al., 1993). However, with respect to irregulars, the results are largely inconsistent. Where Stanners et al. had seen reduced facilitation for irregulars, Kempley and Morton (1982) found no priming at all, whereas Fowler et al. (1985) and Forster, Davis, Schoknecht and Carter (1987) found full priming. Marslen-Wilson et al. (1993) investigated two subclasses of irregular past tense forms: (i) verbs such as burnt–burn and felt–feel with -t as the final consonant, and (ii) verbs such as sang–sing, gave–give with vowel changes only. They compared these irregular types with regular past tense forms in a cross-modal priming task. Only the regular past tense forms produced full priming. The past tense forms of semi-regular verbs (burn–burnt, feel–felt) yielded no priming, whereas those of pure vowel-change verbs such as give–gave actually led to an interference effect, with response times being significantly slower than following unrelated primes. The interference effect might be taken to reflect the presence of different representations for give and gave, for example, which inhibit one another.

Perhaps the strongest evidence for a regular–irregular dissociation in the English past-tense system comes from a cross-modal priming study with English-speaking aphasics (Marslen-Wilson & Tyler, 1997). Marslen-Wilson and Tyler found that one subgroup of subjects exhibited (partial) priming effects for irregulars, but have lost (full) priming of regular verbs; another patient showed exactly the opposite pattern. Thus, there seems to exist a double dissociation between regular and irregular past tense forms in these patients which indicates that the processes underlying regular and irregular inflection can be selectively impaired.

Taken together, the priming data on the English past tense are inconclusive. It is true that in all studies regular past tense forms produced full priming, and this finding is compatible with dual-mechanism models of morphological processing in which regular but not irregular past tense forms are said to be morphologically decomposed. Alternatively, however, Rueckl, Mikolinski, Raveh, Miner and Mars (1997) argued that regular past tense forms are orthographically and phonologically more similar to their base forms than are irregular past tense forms; for example, walked → walk versus taught → teach, and it might be these different form properties that account for full priming of regular past tense forms. This interpretation would be compatible with single-mechanism associative models of the mental lexicon in which morphological structure is not directly encoded.

There are ways of dealing with this confounding factor, but these involve relatively complex designs, such as additional control conditions. Consider, for example, Münte, Say, Clahsen, Schiltz and Kutas (1998), a repetition priming study on the English past tense using event-related potentials (ERPs). To control for the greater degree of prime–target similarity in regulars than in irregulars, Münte et al., added a phonological overlap condition with prime–target pairs of different words, e.g. board–boar, weird–weir, shrewd–shrew, which in terms of formal similarity were as similar to each other as regular past tense forms are to their stems. Despite these similarities, they found different ERP-effects: primed regular verb stems elicited an N400 modulation (i.e. a more positive-going waveform with a centroparietal distribution in the 250–450 ms time window), whereas neither the irregulars nor the phonological overlap condition produced any ERP priming effect. This suggests that the ERP-effect for regular verbs cannot be attributed to low-level formal priming. Furthermore, a number of cross-modal and visual priming studies have shown that formally similar but morphologically unrelated prime–target pairs either lead to inhibition effects or to no priming at all when compared with a baseline condition (Grainger, Cole & Segui, 1991; Drews & Zwitserlood, 1995, among others).

Another potentially confounding factor in priming studies on the English past tense is that only regular past tense forms have a segmentable affix in English. Hence, the observed priming differences between regular and irregular past tense forms could simply be due to a language-specific property of English, namely the lack of a segmentable ending in irregulars.

Finally, frequency is a potentially confounding factor. In English, regular verbs are much more frequent (both in terms of types and tokens) than irregulars. Correspondingly, -ed past tense forms are more frequent than irregular past tense forms; see Marcus, Brinkman, Clahsen, Wiese and Pinker (1995), p. 221 for relevant

frequency counts. Hence, the observed priming differences could be due to the statistical distribution of past tense forms in English, rather than to the regular/irregular distinction per se. In a connectionist network, for example, the effects of the more frequent exposure to -ed forms may cause stronger priming than for irregular past tense forms which are experienced less often and are more affected by neighbouring competitors (see e.g. Plaut, McClelland, Siedenberg & Patterson, 1996). Thus, it is not entirely clear how full priming for regular past tense forms should be interpreted. In addition to that, there remains the question of why irregulars have yielded such inconsistent results across studies.

3. The present study

One approach for resolving the controversy between single and dual-mechanism models is to investigate inflectional systems with more advantageous properties than the English past tense. German inflection is a case in point. Regular and irregular participle and noun plural forms have segmentable endings, and the regular/irregular distinction is not confounded by frequency facts (Marcus et al., 1995). Moreover, there are irregular forms which show the same degree of formal similarity to their base forms as regularly inflected word forms. Such cases (which do not exist in the English past tense) enable us to tease apart regular/irregular differences in morphological priming from potential form–property confounds. If regularly inflected word forms are decomposed into stems and affixes and are accessed via their constituent morphemes, whereas irregularly inflected word forms have full-form representations, we expect to find different priming patterns for regular and irregular inflection. Specifically, we predict that as the decomposition of regularly inflected forms results in direct access to their stems they should exhibit full priming. Despite similar form properties, irregular word forms should not, however, produce full priming, because irregular word forms have lexical entries separate from their stems and can only indirectly access their stem forms.

We tested these predictions in three cross-modal immediate repetition priming experiments, one on participles, one on noun plurals and a control experiment on diminutives. In each experiment, subjects heard a spoken prime immediately followed by a visually presented target form to which they made a word/nonword decision. Subjects were tested on three types of prime–target pairs in each experiment: (i) Identical (e.g. Bild–Bild ‘picture’), (ii) Morphologically Related (e.g. Bilder–Bild ‘pictures–picture’), and (iii) control (e.g. Flugzeug–Bild ‘plane–picture’). The difference between conditions (i) and (ii) on the one hand and conditions (ii) and (iii) on the other is taken as a measure of morphological priming.

4. Past participles

All German past participles are formed by adding a participle suffix to a verbal stem. Regular verbs carry the suffix -t and do not exhibit any stem changes, neither in the participle nor in any other verb form (e.g. öffnen–öffnete–geöffnet ‘open–

opened–opened '). In contrast, participles of irregular verbs are suffixed with -en and may undergo stem changes. Three minor verb classes can be distinguished with respect to stem changes: 'A–B–B' verbs have the same vowel change in the past tense and the participle (e.g. schreiben–schrieb–geschrieben 'write–wrote–written'); 'A–B–C' verbs have two different vowel changes in the past tense and the participle (e.g. gehen–ging–gegangen 'go–went–gone'); and 'A–B–A' verbs have a vowel change in the past tense but not in the participle (e.g. schlafen–schlief–geschlafen 'sleep–slept–slept').

In experiment I, priming effects for participle forms of regular verbs were compared with those of irregular participles of the A–B–A class, using 1st person singular present tense forms as targets in all conditions (e.g. schlafe '(I) sleep'). It is important to note that in our experiment the (participle) primes of irregular verbs (e.g. geschlafen) are at least as similar to their corresponding target forms (e.g. schlafe), both phonologically and orthographically, as the regular (participle) primes (e.g. geöffnet) are to their target forms (e.g. öffne). The prime and target forms of A–B–A verbs have the same syllabic structure, while in some of the regular verbs the syllable structure of prime and target forms is different, as for example in gesagt–sage. Moreover, there are no vowel changes in the participle forms we tested, neither in (irregular) 'A–B–A' participles nor in regular participles. This is in contrast to English past tense forms where stem changes are a confounding variable for potential priming differences between regular and irregular inflection (see Rueckl et al., 1997). Thus, unlike in English, priming differences between regulars and irregulars cannot be attributed to different form properties[1].

We adopted the cross-modal immediate repetition priming paradigm (Marslen-Wilson et al., 1993; Marslen-Wilson, Tyler, Waksler & Older, 1994) in which primes are presented auditorily, and targets are presented visually, for the following two reasons. Firstly, since the task is cross-modal, any priming effects are likely to be due to the lexical representations themselves, rather than to effects of modality-specific access procedures. Secondly, since all targets are presented immediately at the offset of the prime, the task is likely to tap on-line processes of morphological priming, while unwanted effects of episodic memory are reduced[2].

[1] The regular/irregular distinction in German participles is also less confounded with frequency than the English past tense or plural. German has a smaller ratio of regular to irregular verbs than English. Among the thousand most frequent verb types in the two languages, approximately 85% of those in English are regular, compared to approximately 45% of those in German. With larger samples of verbs, the gap narrows, but English always shows the higher proportion (see discussion in Bybee, 1995; Marcus et al., 1995; Clahsen, 1997). As will be shown in experiment II, German plurals provide a much more dramatic case for dissociating regularity from frequency.

[2] Episodic memory effects are based on the participant's remembering of a prior event, rather than prior access to a lexical entry. Such effects are possibly strategic in nature and have been shown to be stronger if the delay between prime and target is longer (Tenpenny, 1995). Thus, the lack of such a delay in the cross-modal priming task helps to reduce episodic memory effects. Episodic memory effects should also be stronger if the participant has to react in the same way to both elements of a related stimulus pair (e.g. by pressing the same response button for the prime as well as for the target). In a cross-modal priming task, however, participants only react to the visually presented targets which should also contribute to reducing episodic memory effects.

4.1. Materials

Forty-two triplets of verb forms were constructed, 21 with regular targets, 21 with A–B–A verbs as targets. The target in all conditions was the 1st person singular present tense form. For each target, three types of primes were used (see Table 1). All targets (see Appendix A) were matched for the number of syllables and for the stem frequency of primes and targets, based on the CELEX database (Baayen, Piepenbrock & van Rijn, 1993).

Because no participant should see the same target more than once, three experimental versions were constructed. The regular and irregular experimental triplets were divided into three groups, matched for mean stem frequency. The prime–target pairs were distributed over the three versions in a Latin square design (Winer, 1971), so that each version included 42 different prime–target pairs (seven from each of conditions I–VI), and no target appeared more than once in any version. In order to dilute the proportion of morphologically related prime–target pairs and to deter the participants from developing expectations about prime–target relations, 462 filler items were constructed. The stimulus set of each version consisted of 504 prime–target pairs:

1. Forty-two pairs of experimental items, 28 of which (11% of the total number of pairs with an existing verb as target) were morphologically related (conditions I, II, IV, and V), 14 of which were unrelated (conditions III, VI).
2. Two hundred and ten pairs of existing German verbs which were unrelated to each other (verb/verb fillers).
3. Twenty-eight verb/pseudo-verb pairs in which the (pseudo-verb) target was formally similar to the prime; in 14 of these pairs the target was fully contained within the prime (e.g. rinnst 'run' –krinnst), and in 14 other pairs the two items partially overlapped (e.g. verneigst 'bow' –barneigst).
4. Two hundred and twenty-four verb/pseudo-verb pairs which were unrelated to each other; pseudo-verbs were constructed by changing two letters of an existing regular or irregular verb.

In the construction of the stimulus set, steps were taken to prevent subjects from developing strategies based on the distribution of regular and irregular verbs or on

Table 1
Example stimulus set: participles

Regular participles: condition		Prime	Target	Number of pairs
I	Identity	öffne (open)	öffne (open)	21
II	Participle	geöffnet (opened)	öffne (open)	21
III	Control	wünsche (wish)	öffne (open)	21
Irregular participles: condition				
IV	Identity	schlafe (sleep)	schlafe (sleep)	21
V	Participle	geschlafen (slept)	schlafe (sleep)	21
VI	Control	beuge (bend)	schlafe (sleep)	21

the distribution of particular word forms. The four possible prime–target combinations of existing regular and irregular verbs (regular/regular, regular/irregular, irregular/regular, irregular/irregular) were each used 63 times. Furthermore, we introduced 2nd sg. present tense forms, in addition to participle and 1st sg. present tense forms, so that each of these three forms appeared equally often as primes and as targets, and each of the nine possible prime–target combinations occurred 28 times, respectively. The purpose of introducing pseudo-verbs such as those in (3) above was to ensure that not all phonologically related pairs had real words as targets. In order to eliminate undesired priming effects across items, the 504 prime–target pairs were pseudo-randomized making sure that no semantic associations of any kind existed between consecutive items, and that not more than four items of the same type (word/pseudo-word) occurred in sequence. Each of the three versions exhibited the same order of experimental and filler items.

4.2. Method

Participants: 60 students of the University of Düsseldorf were paid for their participation in the experiment (30 women and 30 men, mean age 26). None of them participated in more than one experimental version.

Procedure: The primes were spoken by a female native speaker of German and recorded on a digital audiotape. The resulting data were stored on a computer and cut by marking the onsets and offsets of the primes with a sound editor. Each prime was compiled into an audio wav-file. The presentation of the stimuli and the measuring of the reaction times were controlled by the NESU software package (Baumann, Nagengast & Klaas, 1993).

The sequence of stimulus events within each trial was as follows. A fixation point was displayed on a computer screen in front of the participant for 800 ms. The fixation point was followed by a short attention tone (200 ms) and then by the auditory prime word, which were presented over headphones. Immediately at the offset of the (spoken) prime the visual target was presented on a 17-inch computer monitor in Arial 24 point with white letters on a dark background. The target stayed on the computer screen for 200 ms. The measuring of the reaction times began with the presentation of the target. The participants reacted by pressing a green button (for a word) or a red button (for a pseudo-word) on a dual box. The green button was on the right side for right-handed and on the left side for left-handed participants. After a pause of approximately 1500 ms the next trial was initiated.

A written instruction with a detailed description of the task and some examples for prime–target pairs were given to the participants before the experiment. The experiment itself started with a short practice phase. After this phase, the participants had the opportunity to ask questions about the procedure. Two further breaks were provided. During each break and at the end of the experiment, the participants were asked to read a list of 15 words, and to mark those words they had heard during the experiment. For each of these lists, 9 words had been presented as auditory primes in the preceding experiment phase. The remaining 6 words did

not occur in the experiment at all. The answers to this task were not analysed, since it was only included to ensure that the participants paid attention to the auditory stimuli. The overall duration of the experiment was approximately 1 h per subject.

Analysis: Errors, i.e. non-word-responses to existing words and word-responses to non-words, were removed before the statistical analyses. For the test items, the error rate did not exceed 1.2% in any of the six test conditions. One item (plane '(I) plan') was excluded from the analysis because of extremely high and variable reaction times (mean RT 801 ms, SD 323 ms). Mean response times for each of the 60 subjects and each of the 21 items in each condition were then computed. These mean scores were entered into two separate MANOVAs, with the factors 'Prime Type' and 'Verb Type'.

4.3. Results and discussion

Both in the subject and in the item analysis, there was a significant main effect of prime type, $F1(2,118) = 22.63$, $P < 0.001$, $F2(2,38) = 14.48$, $P < 0.001$ and a significant prime type × verb type interaction, $F1(2,118) = 3.89$, $P = 0.023$, $F2(2,38) = 5.38$, $P = 0.009$. There was no significant effect of verb type, $F1(1,59) = 0.14$, $P = 0.71$, $F2(1,19) = 0.15$, $P = 0.705$.

In order to examine these effects further, we calculated overall means for each condition, based on the subject and item analysis, respectively, and compared the means using matched *t*-tests (see Tables 2 and 3).

For both regular and A–B–A verbs, a significant Identity priming effect could be observed: for regular verbs, the mean reaction time for the Identity condition was 30 ms shorter than the mean reaction time for the control condition ($t(59) = 3.22$; $P = 0.002$ for subjects and $t(19) = 2.56$; $P = 0.019$ for items). For A–B–A verbs, it was 57 ms (for subjects)/58 ms (for items) shorter (($t(59) = 3.22$; $P = 0.002$ for subjects and $t(19) = 2.56$; $P = 0.019$ for items).

Furthermore, Tables 2 and 3 show that for both regular verbs and irregular A–B–A verbs, the Participle condition produced significantly shorter reaction times than the control condition; i.e. both regular and irregular participles yielded a priming effect. However, in order to determine whether the participle primes the base stem as effectively as this form itself, one has to compare the Participle condition to the Identity condition, in which the base stem is used as a prime. With respect to this comparison, regular and A–B–A verbs behaved differently: regular verbs showed full priming, i.e. the Participle condition did not differ from the Identity condition. In contrast, the A–B–A verbs exhibited only a partial priming effect: the reaction time of the Participle condition is significantly longer than the reaction time of the Identity condition.

Finally, the mean reaction times for the Identity condition were shorter for irregular verbs than for regular verbs, although this difference was not significant ($t(59) = 1.57$; $P = 0.09$). A difference in the reaction times for the Identity condition is not predicted by any of the morphological processing models under discussion. The difference between regulars and irregulars is rather likely to be due to

Table 2
Mean reaction times in experiment I (subject analysis)

	Identity		Participle		Control
Verb type	Mean RT	Difference participle–identity	Mean RT	Difference participle—control	Mean RT
Regular	581	0; $t(59) = 0.06$; $P = 0.956$	581	-30; $t(59) = 4.61$; $P = 0.000$	611
Irregular	563	32; $t(59) = -3.36$; $P = 0.001$	595	-25; $t(59) = 2.97$; $P = 0.004$	620

Table 3
Mean reaction times in experiment I (item analysis)

	Identity		Participle		Control
Verb type	Mean RT	Difference participle–identity	Mean RT	Difference participle—control	Mean RT
Regular	581	0; $t(19) = -0.01$; $P = 0.990$	581	-30; $t(19) = 3.88$; $P = 0.001$	611
Irregular	564	31; $t(20) = -3.13$; $P = 0.005$	595	-27; $t(20) = 2.18$; $P = 0.042$	622

properties of the lexical items involved. Crucially, however, such properties of individual lexical items cannot account for the observed differences in the size of morphological priming effects, since the difference between full and partial priming effects is determined by comparing the same lexical item in the experimental and in the identity condition.

The finding that the presentation of regular participles led to full priming, whereas A–B–A verbs produced only a partial priming effect, is not what one would predict from single-mechanism models of inflection which assume that regular and irregular word forms are represented in the same way. Notice in particular that the observed difference in the size of the priming effect cannot be due to differences in the form properties of the participles: the A–B–A participles, which only yielded a partial priming effect, were as similar to their respective target forms as the regular participles were to their targets. Thus, Rueckl et al.'s (1997) account of the priming differences between regular and irregular past tense forms in English (in terms of form property differences) does not explain the present set of findings[3].

Our finding that regular participles yield full priming is consistent with previous findings on regular past tense forms in English. In contrast to regulars, we found that irregular participles did not fully prime their corresponding visual target forms despite very similar form properties. These results, we believe, support dual-mechanism models of inflection and in particular, the distinction between lexically based (irregular) and affixation-based (regular) inflection. Regulars are decomposed into stems and affixes and therefore prime their stems just as effectively as the stems themselves; irregulars have separate lexical entries and therefore prime their stems only via spreading activation, i.e. partially.

5. Noun plurals

The purpose of this experiment is to determine whether the results on participles generalize to other classes of inflected words. We therefore investigated regular and irregular noun plurals of German, specifically -s and -er plurals, using a cross-modal priming task like in experiment I. An interesting property of German noun plurals is that they have a low-frequency default, i.e. the plural form that most clearly acts as such is in a slight minority compared to the irregular ones. English

[3] Notice, incidentally, that even in English, regular/irregular differences in priming cannot simply be attributed to differences in form properties. First, it is not generally the case that regular past tense forms are more similar to their stems than irregular past tense forms. Some irregular past tense forms are in fact identical to their stems (e.g. hit, put), and past tense forms of pure vowel-change verbs such as gave, rang, and sang differ from their stem forms in just one segment (i versus a). In contrast, all regulars differ from their stem forms in two letters (-ed). Second, the results obtained by Marslen-Wilson et al. (1993) suggest that a higher degree of phonological similarity does not necessarily lead to stronger priming effects. If this were the case, pure vowel-change verbs such as give, ring, and sing should produce larger priming effects than semi-regular verbs such as feel, keep, etc. which exhibit a change of the final consonant in addition to the vowel change. However, Marslen-Wilson et al. obtained the opposite result, an interference effect for vowel change verbs, when compared with semi-regulars.

does not have minority regulars. Both in the past tense and in the plural system of English, regular forms clearly outnumber the irregular ones. Hence, observed differences between regulars and irregulars in English, for example in terms of priming patterns, might be due to the statistical distribution of these word forms rather than to a fundamental regular/irregular distinction as suggested in dual-mechanism models of inflection; see Marcus et al. (1995) for a detailed discussion. German noun plurals allow us to dissociate the role of grammatical regularity from potential frequency effects.

German has a zero plural form and four overt plural suffixes (-e, -er, -(e)n, -s), some of which can co-occur with an altered (umlauted) stem vowel. The use of the different plural allomorphs with specific nouns is arbitrary to varying degrees. There exist, at best, preferred tendencies of plural formation interacting with the gender system and the phonological form of the singular form. For example, masculine and neuter nouns ending with final schwa syllables such as -er and -el usually form the plural with zero, yet plural forms such as Bauern 'farmers', Vettern 'cousins', Muskeln 'muscles', and Pantoffeln 'slippers' exist as well.

The form that acts most clearly as the default is the plural -s, even though this plural allomorph is extremely rare in German. In English, -s is applied to more than 99% of all nouns; in German, -s is applied to only about 7% of nouns. Despite these enormous frequency differences, the two suffixes behave quite similarly in different generalization contexts (see Marcus et al., 1995). The use of the -s plural is not restricted in any way. It occurs on masculine, feminine, and neuter nouns, on words that are part of the canonical stress pattern and on those that are not, on monosyllables and polysyllables, on both vowel-final and consonant-final stems, and when the phonological environment does not permit any other plural allomorph. The -s plural also generalizes to novel, unusual-sounding words, and to rootless and headless nouns derived from other categories, e.g. nominalized conjunctions (die Wenns und Abers 'the Ifs and Buts'), to eponyms and product names (Golfs, Kadetts), and to nominalized VPs (die Rühr-mich-nicht-ans 'the touch-me-nots'). German-speaking children frequently overregularize the suffix in errors such as *Manns (instead of Männer) analogous to English-speaking children's *mans, despite the relatively few nouns in German speech taking an -s plural. In contrast to the plural -s, irregular plural forms are restricted to particular morphophonological conditions and are only tentatively generalized to novel words, particularly to items with high similarity to existing irregular plural forms. For example -er applies predominantly to neuter nouns, never to feminine nouns, and is not used in children's overregularization errors, despite the fact that -er and -s plurals are similar in terms of their frequency distribution. Many of these effects have been corroborated in experiments with German-speaking adults (Marcus et al., 1995) and children (Clahsen, Rothweiler, Woest, & Marcus, 1992; Clahsen, Marcus, Bartke, & Wiese, 1996; Clahsen & Rothweiler, 1993).

In the present experiment, we compare priming effects of (regular) -s plurals and (irregular) -er plurals. Notice that both plural forms have low type and token frequencies of less than 8% (see Clahsen et al., 1996, p. 121). Moreover, both plural forms have a segmentable affix, -s and -er, respectively. Thus, potential priming

differences between -er and -s plurals are not confounded by frequency and by morphological decomposability.

There is, however, one important difference between -s and -er plurals. Whereas -s plurals never involve any stem changes, -er plurals often co-occur with an altered stem vowel, e.g. Blatt–Blätter 'leaf–leaves'. This is due to a phonological rule which fronts the stem vowel of an -er plural form, unless the stem already contains a front vowel, as for example in Kind–Kinder 'child–children'. Because of these properties, the two critical conditions in the present experiment inevitably had differences in the degree of formal (phonological and orthographic) similarity between prime and target stimuli (consider, for example, the irregular pair Blatt–Blätter 'leaf–leaves' and the regular pair Echo–Echos 'echo–echos'). In order to independently assess the role of stem changes (specifically umlaut) for priming, we performed a third cross-modal priming experiment (see experiment III below) using German diminutives which, as will be shown below, allows us to dissociate grammatical regularity from effects of formal similarity.

Returning to -s versus -er plurals, we would expect from a dual mechanism perspective that (regular) -s plurals but not (irregular) -er plurals produce full priming. Regulars are claimed to be decomposed into stem and affix, whereas irregulars form separate lexical entries. Hence, -s plurals should prime their stems as effectively as the stem itself, whereas -er plurals should access their stems only indirectly and should therefore not produce full priming.

5.1. Materials

60 triplets of noun plural forms were constructed, 30 with nouns that take -s plurals and 30 with nouns that take irregular -er plurals[4]. The target in all conditions was the stem (singular) form of the noun. For each target, three types of prime were used (see Table 4).

The experimental items (see Appendix B) in each condition were matched for stem frequency (based on the CELEX database) and syllable count, for -s plurals as well as for -er plurals. However, since nouns which take -s plurals tend to have lower frequencies in German than nouns that take -er plurals (CELEX mean lemma frequencies are 52 for -s plurals and 563 for -er plurals), the lemma frequencies of the nouns we used for -er plurals were higher (CELEX mean lemma frequency 538) than those of the nouns with -s plurals (CELEX mean lemma frequency 43). We would expect this difference to lead to shorter lexical decision times for nouns

[4] Notice that both, -er and -s forms are polyfunctional in German and are not unique to the plural. Comparative adjectives and agentive nouns, for example, are formed with -er, genitive singular forms of masculine and neuter nouns take -s. The endings -t and -(e)n studied in the previous experiment are also polyfunctional in this sense; -t is, for example, used in 3rd sg. present tense forms, and -(e)n in 3rd and 1st plural forms and in infinitives. Thus, polyfunctionality of an affix does not provide a relevant condition to distinguish the regular and irregular forms used in our experiments and to explain potential regular/irregular differences in priming.

Table 4
Example stimulus set: plurals

-s plurals: condition		Prime	Target	Number of pairs
I	Identity	Karton (box)	Karton	30
II	Plural	Kartons (boxes)	Karton	30
III	Control	Spalier (trellis)	Karton	30
-er plurals: condition				
IV	Identity	Bild (picture)	Bild	30
V	Plural	Bilder (pictures)	Bild	30
VI	Control	Flugzeug (aircraft)	Bild	30

that take -er plurals in each of the three experimental conditions, especially in the unprimed control condition. Morphological priming effects, however, are not determined by directly comparing -s and -er plurals, but are measured within target sets, that is by comparing the same targets in the experimental, identity and control condition. As this is done separately for -s plurals and for -er plurals, the different lemma frequencies mentioned above should not affect the priming results.

The experimental prime–target pairs were distributed over three stimulus sets, so that no participant saw the same target more than once. In order to keep the proportion of related pairs below 15% and to deter the participants from developing strategies based on expectations about likely relations between primes and targets, 220 semantically and morphologically unrelated noun/noun pairs and 280 noun/pseudo-noun pairs were added to each of the three stimulus sets. The 220 filler pairs of existing nouns showed different morphological patterns. 40 of the items were feminine nouns with the derivational suffix -in (e.g. Managerin 'female manager'), 40 were compound nouns (e.g. Zeitschrift 'newspaper'), 50 items had a diminutive suffix (e.g. Fingerchen 'small finger'), 50 items were nouns with plurals other than -er or -s (e.g. Schwestern 'sisters') and 40 were uninflected singular noun pairs (e.g. Bürste 'brush' –Zigarre 'cigar'). In each filler condition, the morphologically complex nouns appeared equally often as primes and as targets. Among the 280 noun/pseudo-noun pairs, we included 20 pairs in which the non-word target fully contained the prime (e.g. Erbse 'pea' –Berbser) and 20 pairs in which the prime and the non-word target partially overlapped (e.g. Demokrat 'democrat' –Demolurst). This was done to ensure that not all phonologically related pairs had real words as targets. The remaining 240 pseudo-nouns were constructed by changing two or three letters of an existing noun.

There was a total of 560 prime–target pairs in each stimulus set; these were pseudo-randomized with the same order of experimental and filler items in each of the three versions.

5.2. Method

The methods, procedures and time settings for this experiment were taken over

from experiment I. 66 students of the University of Düsseldorf were paid for their participation in the experiment, 22 per version (35 women and 31 men, mean age 25). None of the subjects participated in more than one experimental version.

Analysis. Errors, i.e. non-word-responses to existing words and word-responses to non-words, were removed before the statistical analyses. The mean error rate for the test items was 1.2%. The mean response times for each subject and each item were entered in two separate MANOVAs, with the factors 'Prime Type' and 'Plural Type'.

5.3. Results and discussion

Both in the subject and in the item analysis, there were significant main effects of prime type ($F1(2, 130) = 97.70$, $P < 0.001$ for subjects, $F2(2, 58) = 46.97$, $P < 0.001$ for items), and plural type ($F1(1, 65) = 65.62$, $P < 0.001$ for subjects, $F2(1, 29) = 12.60$, $P = 0.001$ for items), as well as a significant prime type × plural type interaction, with $F1(2, 130) = 27.18$, $P < 0.001$ for subjects and $F2(2, 58) = 9.27$, $P < 0.001$ for items. Tables 5 and 6 present overall means for each condition and statistical comparisons using *t*-tests.

Tables 5 and 6 show that nouns that take -er plurals produced much shorter mean RTs in all three conditions than nouns that take -s plurals, yielding a significant main effect of 'Plural Type'. We attribute this effect to the different lemma frequencies of the items involved. Frequency effects should be most obvious from the lexical decision times of the unprimed control condition, and as Table 5 shows, it is indeed this condition that produced a massive 84 ms difference between -s and -er plurals.

With respect to morphological priming, Tables 5 and 6 show results that are parallel to those of experiment I. For both types of noun, those that take -s and those that take -er plurals, the Identity and the plural condition produce significantly shorter RTs than the control condition. The size of the priming effect, however, differs for regular and irregular plurals. Regular (-s) plurals gave rise to full priming, i.e. the plural condition for regulars produced significantly shorter RTs than the control condition, but it did not significantly differ from the Identity condition. In contrast, -er plurals exhibited only a partial priming effect with the mean RT of the (irregular) plural condition being significantly longer than the mean RT for the Identity condition. These results confirm the predicted priming differences between regulars and irregulars and are consistent with the distinction between lexically based (irregular) and affixation-based (regular) inflection as suggested in dual-mechanism models of inflection.

Consider potentially confounding factors and alternative explanations for the observed priming differences between -er and -s plurals in our experiment. Note first that the application of the irregular plural marker -er always changes the syllabic structure of the root whereas the affixation of the regular plural marker -s never does; consider e.g. Kind–Kin + der ('child–children') or Blatt–Blät + ter ('leaf–leaves') versus Ki + no–Ki + nos ('cinema–cinemas'). The lack of full priming in -er plurals might perhaps be due to this difference in syllable structure. If this were

Table 5
Mean reaction times in experiment II (subject analysis)

	Identity		Plural		Control
Plural type	Mean RT	Difference plural–identity	Mean RT	Difference control–plural	Mean RT
-s plurals	575	6; $t(65) = 0.86$; $P = 0.394$	581	95; $t(65) = 9.62$; $P < 0.001$	676
-er plurals	545	19; $t(65) = 3.10$; $P = 0.003$	564	28; $t(65) = 4.60$; $P < 0.001$	592

Table 6
Mean reaction times in experiment II (item analysis)

	Identity		Plural		Control
Plural type	Mean RT	Difference plural–identity	Mean RT	Difference control–plural	Mean RT
-s plurals	575	6; $t(29) = 0.56$; $P = 0.582$	581	100; $t(29) = 5.41$; $P < 0.001$	681
-er plurals	547	17; $t(29) = 2.29$; $P = 0.029$	564	18; $t(29) = 3.66$; $P = 0.001$	593

the case, however, we would expect to find a parallel effect in participles. Thus, A–B–A participles (which have the same syllabic structure as their corresponding targets) should produce full priming, whereas regular participles (some of which have a different syllabic structure than their corresponding targets) should produce partial priming. The results of experiment I do not confirm this prediction. Regular participles produced full priming (despite differences in syllable structure), and irregular participles did not produce full priming (even though they had the same syllable structure as the corresponding targets); see also Marslen-Wilson et al. (1994) for related results on English. We conclude that differences in syllable structure cannot account for the observed priming differences.

A second potentially confounding factor could be that about 25% of the targets of the -er plural set were derived nouns, whereas none of the -s plurals were derived forms. Suppose derived word forms are stored as full forms (Stanners et al., 1979, among others), then the observed partial priming effect for -er plurals could be attributed to these stimuli. However, a post hoc comparison of the mean RTs for monomorphemic versus derived nouns in our dataset shows that the priming effect is even larger for -er plurals of derived nouns (identity 540 ms, SD 120; plural 554 ms, SD 106; control 579 ms, SD 103) than for -er plurals of monomorphemic nouns (Identity 528 ms, SD 114; plural 549 ms, SD 118; control 566 ms, SD 112). Hence, the overall partial priming effect for -er plurals cannot be attributed to the derived nouns in our stimulus set.

Finally, recall that -er plurals often involve stem changes and are therefore less similar to their stems than -s plurals, which never have stem changes. The priming differences between -er and -s plurals could therefore be explained in terms of different degrees of formal overlap between primes and targets in the stems of regular and irregular plurals. However, a comparison of responses to -er plurals with and without stem vowel changes suggests that this is not the case. We found that -er plurals without stem vowel change (e.g. Kind–Kinder) produced a (partial) priming effect of 28 ms (Identity 520 ms, SD 117; plural 548 ms, SD 118; control 574 ms, SD 105), whereas -er plurals with stem vowel change (e.g. Wald–Wälder) showed a (partial) priming effect of only 18 ms (Identity 533 ms, SD 114; plural 551 ms, SD 117; control 566 ms, SD 113). If the size of morphological priming effects were due to formal similarity, we would have expected the opposite pattern. As there are not enough -er plurals without vowel changes in German to allow for a reliable statistical comparison, we will address the role of stem changes for priming in a separate experiment using diminutive forms.

6. Diminutives

In this experiment, we investigate the role of stem changes for priming, independently of the distinction between regulars and irregulars. The results of this experiment should help us to tease apart effects of grammatical regularity from potential form-property confounds, specifically those in experiment II.

German diminutive formation provides the relevant linguistic properties for this

purpose. The formation of diminutives in German is fully regular, semantically transparent and highly productive, and yet diminutive forms exhibit exactly the same stem changes as -er plurals. The umlauted stems in these cases can be assumed to be due to a phonological rule of fronting that is conditioned by both the -er plural affix and the diminutive affixes. This rule changes any back vowel to a fronted (umlauted) vowel while maintaining all other vowel properties (Wiese, 1996). Consider the following examples[5]:

	Stem	Diminutives	Plurals
a	Dach (roof)	Dächlein	Dächer
b	Strauch (bush)	Sträuchlein	Sträucher
c	Rad (wheel)	Rädchen	Räder

In order to examine the role of formal similarity and the potential effects of umlauted stems on priming, we performed a cross-modal priming experiment in which the priming patterns of vowel-change diminutives (such as those in (a) to (c)) were compared with those of diminutives without stem changes (such as Kind–Kindchen 'child–small child'). If priming is determined by formal similarity under these circumstances, then diminutives with umlauted stems should produce a smaller priming effect than diminutives that do not have stem changes. Since the stem changes that occur in diminutives are the same as those in -er plurals, the outcome of the diminutives experiment will allow us to reconsider the results of experiment II and to decide whether the priming differences between -s and -er plurals are caused by stem changes or by differences in grammatical regularity.

6.1. Materials

60 triplets of diminutive forms were constructed, 30 with an altered (umlauted) stem and 30 without a stem change. The target in all conditions was the stem (singular) form of the noun. For each target, three types of prime were used (see Table 7). The items with and without umlaut (see Appendix C) were matched for stem frequency (based on the CELEX database) and syllable count.

The construction of the materials (ratio of related and unrelated prime–target pairs, filler items) was parallel to the previous experiments. As word-word fillers we included different kinds of morphologically complex words, e.g. 50 feminine nouns with the derivational suffix -in, 50 compound nouns, and 50 noun plurals; there were also 30 prime–target pairs containing a diminutive form as target which was unrelated to the prime (to counterbalance the related diminutives in the experi-

[5] Two suffixes (-chen and -lein) are available for diminutive formation. The choice between -chen or -lein is largely free, even though there are regional preferences for one of the two forms. The more common suffix is -chen. Both diminutive suffixes co-occur with altered (umlauted) stems.

Table 7
Example stimulus set: diminutives

		Prime	Target	No. of pairs
Diminutive without umlaut				
I	Identity	Schirm (umbrella)	Schirm	30
II	Diminutive	Schirmchen (small umbrella)	Schirm	30
III	Control	Streusel (crumbs)	Schirm	30
Diminutive with umlaut				
IV	Identity	Haus (house)	Haus	30
V	Diminutive	Häuschen (small house)	Haus	30
VI	Control	Boykott (boykotting)	Haus	30

mental conditions). Half of the morphologically complex nouns were presented as primes, the other half as targets, and for each word–word pair a corresponding pair with a pseudo-word as target was included. The experimental prime–target pairs were distributed over three versions, so that no participant saw the same target more than once. There was a total of 560 prime–target pairs in each stimulus set; these were pseudo-randomized with the same order of experimental and filler items in each of the three versions.

6.2. Method

The methods, procedures, and time settings for this experiment were taken over from experiment I. 63 students of the University of Düsseldorf were paid for their participation in the experiment, 21 per version (32 female and 31 male, mean age 26). None of the subjects participated in more than one experimental version.

Errors, i.e. non-word-responses to existing words and word-responses to non-words, were removed before the statistical analyses. The error rate for the test items did not exceed 1% in any of the test conditions. The mean response times for each subject and each item were entered in two separate MANOVAs, with 'Prime Type' (identity, diminutive, control) and 'Stem Type' ($\pm$umlaut) as factors.

6.3. Results and discussion

We found a significant main effect of prime type, both in the subject and in the item analysis ($F1(2, 124) = 33.38$, $P < 0.001$ for subjects, $F2(2, 58) = 24.26$, $P < 0.001$ for items). By contrast, there was no significant main effect for stem type ($F1(1, 62) = 1.22$, $P = 0.273$ for subjects, $F2(1, 29) = 0.62$, $P = 0.441$ for items) and no significant prime type $\times$ Umlaut interaction ($F1(2, 124) = 0.13$, $P = 0.88$ for subjects, $F2(2, 58) = 1.16$, $P = 0.323$ for items). Tables 8 and 9 present the overall means for each condition and statistical comparisons using *t*-tests.

For both stem types, the Identity and the diminutive conditions produced signifi-

Table 8
Mean reaction times in experiment III (subject analysis)

	Identity		Diminutive		Control
Stem type	Mean RT	Difference diminutive–identity	Mean RT	Difference control–diminutive	Mean RT
With umlaut	492	7; $t(62) = 1.48$; $P = 0.145$	499	28; $t(62) = 4.56$; $P < 0.001$	527
Without umlaut	497	7; $t(62) = 1.24$; $P = 0.219$	504	24; $t(62) = 3.85$; $P < 0.001$	528

Table 9
Mean reaction times in experiment III (item analysis)

	Identity		Diminutive		Control
Stem type	Mean RT	Difference diminutive–identity	Mean RT	Difference control–diminutive	Mean RT
With umlaut	492	7; $t(29) = 1.46$; $P = 0.156$	499	28; $t(29) = 4.25$; $P < 0.001$	527
Without umlaut	496	8; $t(29) = 1.01$; $P = 0.326$	504	24; $t(62) = 3.40$; $P < 0.001$	528

cantly shorter RTs than the control condition causing the prime type effect mentioned above. More importantly, however, the size of the priming effect in the diminutive condition does not significantly differ from the Identity condition, neither for diminutives with umlauted stems (488 ms versus 495 ms, n.s.), nor for diminutives without stem changes (493 ms versus 498 ms, n.s.). Thus, the formal differences between the two types of diminutives had no effect on their priming patterns. Diminutives fully prime the basic stem (singular) form of the corresponding noun, irrespective of whether the diminutive contains an umlauted stem or a stem without a vowel change. These results show that (other things being equal) umlauting of the stem vowel does not affect the magnitude of morphological priming. This should also be the case for -er plurals, since they involve exactly the same kind of stem changes as diminutives. Thus, the reduced priming effect we found for -er plurals in experiment II cannot be attributed to the fact that they sometimes have umlauted stems. This leaves us with an account of the priming differences between -er and -s plurals in terms of grammatical regularity: regular -s plurals are decomposed into stem + affix and therefore fully prime their stems, irregular -er plurals, however, have separate lexical entries, and the priming route is therefore less direct than for -s plurals.

Our results on diminutives are also relevant to the controversial issue of how derivational forms are represented in the mental lexicon (Stanners et al., 1979; Fowler et al., 1985; Feldman, 1994; Marslen-Wilson et al., 1994; Alegre & Gordon, 1996, among others). Previous studies involving inflectional and derivational primes have produced inconclusive results. Derivational forms typically produced smaller priming effects towards corresponding stem forms than regularly inflected primes, but the difference was often not statistically significant (Feldman, 1994 for an overview). Some authors have taken these findings to indicate that derived forms are not accessed via their constituent morphemes, but rather stored as full forms (Stanners et al., 1979, among others). This claim is not supported by our findings. The full priming effect we found for both types of diminutive forms indicates that these forms are decomposed into stems and affixes and thus can directly access their stems. This finding is reminiscent of the results of Marslen-Wilson et al. (1994) on English. They showed that semantically transparent derived words in English prime their stems in the cross-modal priming task and that stem changes did not have any negative effects on priming. In one of their experiments, Marslen-Wilson et al. (1994, p. 7ff.) found, for example, that the amount of priming for high-similarity pairs such as friendly/friend is not significantly greater than for pairs which involve a vowel change (serenity/serene). On the basis of this result and several control experiments, they ruled out the possibility that simple formal overlap between prime and target caused the priming effects, and they concluded that priming is due to events at the level of the lexical entry. Our results on German diminutives confirm the findings of Marslen-Wilson et al. on English and can be accounted for in the same way as their findings, i.e. in terms of shared lexical entries of stems with and without vowel changes and by assuming that at least semantically transparent and highly productive derived word forms are accessed via their constituent morphemes.

7. General discussion

The dispute between single and dual mechanism models of inflection raises the question to what extent the representation and processing of inflected words is universal across languages and to what extent it depends on properties that are specific to individual languages. Under a strong universalist interpretation of the dual-mechanism hypothesis, for example, one would expect that inflected words be either affixation-based or lexically based, i.e. stored in lexical entries. If, on the other hand, connectionist single-mechanism models hold universally, all inflected words should be associatively represented, independently of language-particular differences. Clearly, these predictions can only be investigated by comparing the processing of regular and irregular inflection across different languages. Even though there is currently not enough evidence to give any definitive answers, we believe that some tentative cross-linguistic generalizations can be made.

As pointed out above, the results from morphological priming studies on English are not fully conclusive. Priming patterns for irregulars were inconsistent across studies. Regulars, by contrast, consistently yielded full priming effects, but the significance of this effect for the theoretical controversy between single and dual-mechanism models of inflection is not entirely clear, due to a number of confounding factors.

7.1. German inflection

German participle and noun plural inflections have properties which render them more amenable than the English past tense to teasing apart regular/irregular differences in inflectional processing and representation from potentially confounding factors. Recall that in German regular and irregular forms both have segmentable endings, that regulars do not outnumber irregulars in terms of their vocabulary distribution and that there are irregular forms which show the same degree of formal similarity to their base forms as regulars. Despite these similarities in terms of word form, frequency distribution and phonological/orthographical form, in the present paper we found clear priming differences between regulars and irregulars in German participles and noun plurals.

Single-mechanism models that do not distinguish between regular and irregular inflection provide only partial explanations for the priming effects we found. In connectionist models of inflection, priming effects of inflected words have been claimed to vary in strength depending on the degree to which prime–target pairs are formally similar (Rueckl et al., 1997). While this might indeed be the case for English past-tense forms, the German participle forms we examined in experiment I do not differ in this respect. Thus, a participle of the A–B–A class (e.g. geschlafen ‘sleep’) is as similar to its base form (schlaf-) as a regular participle (e.g. geöffnet ‘opened’) is to its base stem (öffn-), and despite these formal similarities the regular form produced full priming, and the irregular one did not. We also

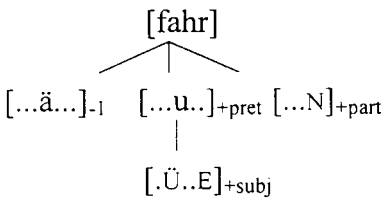
found full priming effects for regular but not for irregular German noun plurals (-s versus -er), in experiment II. These two types of plural, however, were inevitably different from each other in terms of the degree of formal overlap with their corresponding stem forms; the irregulars have altered (umlauted) stems whenever possible, e.g. Rad–Räder 'wheel–wheels', whereas -s plurals never have any stem changes. To control for the potential priming effect of umlauted stems in German, we examined diminutives in an additional experiment. Recall that diminutives exhibit the same kind of stem changes as -er plurals. Despite this similarity, we found that all diminutives, even those with umlauted stems, fully prime their corresponding base forms, whereas irregular -er plurals only produced partial priming. Thus, the priming differences between regulars and irregulars we found for German participles and noun plurals are unlikely to be caused by the degree of formal similarity between prime and target. This, as far as we can see, leaves a connectionist single-mechanism account with no explanation for the priming effects found in experiments I and II.

Another variant of a single-mechanism model of inflection (see e.g. Taft & Forster, 1975; Taft, 1979, 1988; Taft & Hambly, 1986) that does not distinguish between regular and irregular inflection claims that all polymorphemic words undergo parsing operations. Recall that all the participle and noun plural forms we tested have segmentable endings, both for regulars and irregulars. As they are decomposable, Taft's obligatory decomposition model would lead us to expect that regular and irregular German participles and noun plurals undergo affix stripping and stem access. If that were the case, the observed priming differences between regulars and irregulars are hard to explain. Taft (personal communication) pointed out to us, however, that the regularity difference in the priming effect could be explained in his revised decompositional model (Taft, 1994), by claiming that irregular forms have their own representation, i.e. the whole inflected word, whereas there is no such representation for regularly inflected forms so that these forms have to be generated from their stems. Thus, the representation accessed for irregular forms is different to that accessed for regular forms, and hence the observed differences in priming. This suggestion is indeed compatible with our (dual-mechanism) account of the priming data in that it postulates the availability of different representations for regulars and irregulars, decomposed representations for the former and whole-word based representations for the latter.

According to dual-mechanism models of inflection, regular forms are based on affixation whereas irregulars are stored in lexical entries; see, for example, the distinction between words and rules in Pinker (1999). Wunderlich and Fabri (1995) have presented a linguistic analysis of German inflection in this framework. Two distinct mechanisms are posited, affixation processes such as (i) and several templates for lexical entries such as the one in (ii).

$$\text{(i)} \quad /\text{-}t/; \quad [+\mathrm{V}] \quad \rightarrow \quad [\ ]_{+\mathrm{part}}$$

(ii)



'to drive'

Regular participle inflection involves suffixation of -t to a verb stem to form participles such as geöffnet 'opened'. Irregular participle forms, on the other hand, are represented in terms of structured lexical entries such as the one in (ii). Hence, an irregular verb of the A–B–A class (such as those used in experiment I) has one base node (fahr) and several subnodes, e.g. fuhr for past tense formation and (ge)fahren for participles, whereas the lexical entries of regular verbs do not contain any subnodes; a regular verb like öffnen 'to open' for instance has just one base node (öffn-), and the participle inherits the feature structure of this general entry. Wunderlich and Fabri's analysis of German inflection has also been applied to noun plurals (see Clahsen, 1999 for discussion). Given this analysis, the processing of regulars can be conceived of in terms of computational operations to form stem + affix combinations, while the processing of irregulars involves a lexical look-up. Our priming results support this distinction. Regulars are decomposed and can directly access their stems, hence the full priming effects in our experiments. Irregulars are stored as sub-entries in the lexicon and can only indirectly activate their corresponding base forms, hence the lack of full priming in irregulars. In this way, a dual-mechanism model of inflection and in particular the distinction between lexically based and rule-based inflection accounts for our priming results.

7.2. Italian inflection

Despite the fact that German has some suitable properties for investigating differences between regular and irregular inflection, the question remains of how general this distinction is across languages. After all, German and English are typologically closely related, belonging to the same family of (Germanic) languages. Thus, it might be the case that the regular/irregular distinctions found in these two languages reflect a phenomenon that is specific to Germanic languages, rather than to languages in general. In several recent studies, Italian past-tense and participle inflections were examined with respect to these issues (Orsolini & Marslen-Wilson, 1997; Cappa & Ullman, 1998; Say, 1998; Gross, Say, Kleingers, Münte, & Clahsen, 1998).

In contrast to Germanic languages, Italian verbs fall into three basic morphological classes, called conjugations. Each of these conjugations is identified by a thematic vowel (-a, -e, -i) which follows the verb root and with it forms the verb stem. Inflectional endings are suffixed to the verb stem. Conjugation I verbs are for

the most part fully regular in that they exhibit no stem changes and have segmentable affixes, e.g. am-a-re, am-a-to, am-a-rono 'to love, (have) loved, (they) loved'. The majority of conjugation II verbs have irregular past participles or past tenses (or both) in that these undergo stem changes and sometimes also take irregular inflectional endings, e.g. perd-e-re, perso, persero 'to lose, (have) lost, (they) lost'. Conjugation III verbs are mostly regular, but around 10% have irregular past participles or past tenses (or both), e.g. apr-i-re, aper-to, apr-i-rono 'to open, (have) opened, (they) opened', d-i-re, detto, dissero 'to say, (have) said, (they) said'.

In their study of Italian patients with Alzheimer's disease, Cappa and Ullman (1998) found that the patients were worse at producing present tense and past participle forms of 2nd conjugation verbs than 1st conjugation verbs. This falls in line with the observation that English-speaking Alzheimer patients are worse at irregular than regular past tense production (Ullman, Corkin, Coppola, Hickok, Growdon, Koroshetz & Pinker, 1997) and suggests a regular/irregular distinction for verb forms in Italian.

On the other hand, Orsolini and Marslen-Wilson (1997) claimed to have found evidence against the applicability of dual-mechanism models to Italian and argue that regular and irregular inflection does not involve qualitatively different types of morphological processes in Italian. In their priming experiment, subjects heard a past-tense form which was immediately followed by a visually presented infinitive form or past participle form of the same verb to which a lexical decision response was made. Orsolini and Marslen-Wilson found that the priming generated by regularly inflected pairs (their conditions 1 and 2) did not significantly differ from the priming generated by pairs in which the prime was an irregular form (their conditions 3 and 4). This finding, they conclude, challenges dual-mechanism models of inflection.

However the design of Orsolini and Marslen-Wilson's experiments does not clearly differentiate between the formation of stems and affixation, and the group of verbs classified as regular in their experiment (conditions 1 and 2) included both 1st and 3rd conjugation verbs, classes which have independently been shown to exhibit divergent generalization properties (Say, 1998). In an elicited production experiment, Say found that 1st conjugation stem forms generalize freely to all types of novel verbs, regardless of phonological content, whereas 3rd and 2nd conjugation stems, even those which were classified as regular in Orsolini and Marslen-Wilson's study, generalize only to those novel verbs that were similar to existing verbs of these types. Moreover, a frequency effect was found for 3rd and 2nd conjugation verbs, but not for 1st conjugation verbs: the former generalize more easily to novel verbs that were similar to existing high-frequency verbs than to those based on low-frequency existing verbs. Thus, only the 1st conjugation stem formation process showed characteristics of a default; the 2nd and 3rd conjugation stem forms, on the other hand, showed non-default behaviour, namely frequency and similarity effects in their generalization properties. These results may also have a bearing on morphological priming patterns of Italian verb stems. Orsolini and Marslen-Wilson argued that there are no priming differences between regular and irregular verbs in Italian, but they did not distinguish between 1st and 3rd conjugation stems. If, however,

following Say (1998), only 1st conjugation stems are defaults, different priming patterns for 1st and 3rd conjugation forms are to be expected, full priming for the former and partial priming for the latter. In any case, by teasing apart 1st and 3rd conjugation stem forms, we might be able to see potential regular/irregular distinctions in priming more clearly.

In addition to stem formation processes, the role of affixation processes in Italian verb forms has been investigated, using the ERP violation paradigm (Gross et al., 1998). ERPs were recorded while 12 Italian-speaking subjects read correctly and incorrectly inflected participle forms of verbs of the 1st, 2nd, and 3rd conjugation class. Incorrect irregulars resulting from overgeneralizations of the regular -t participle affix, e.g. *prendato '*tooked' instead of the correct preso 'taken', elicited a widespread early negativity. This results is similar to previous ERP results on German participle (Penke, Weyerts, Gross, Zander, Münte, & Clahsen, 1997) and plural inflection (Weyerts, Penke, Dohrn, Clahsen & Münte, 1997). Affixation of the participle -t in Italian and German and of the plural -s in German involves a rule by which an affix is combined with a stem. Our studies, both on Italian and German, indicate that overapplications of affixation rules yield corresponding ERP-effects.

Further experimentation is required before any strong cross-linguistic claims on the processing of inflection can be made. This caveat notwithstanding, we think that the results mentioned above do indeed suggest that across different types of languages the mind/brain honours the regular/irregular distinction posited by dual-mechanism models of inflection, through different priming patterns, different generalization properties and different brain potentials for the two morphological clusters.

8. Conclusion

We found clear priming differences between regularly and irregularly inflected German words. Regularly inflected forms (-s plurals and -t participles) produced full priming, while irregulars (-er plurals and -n participles) were much less efficient primes. An additional experiment (on diminutives) demonstrated that the priming differences in the plural study are unlikely to have been caused by form–property differences between regular and irregular word forms. Several other potentially confounding factors were ruled out. We propose a dual-mechanism account for the observed priming difference: -s plurals and -t participles are based on affixation rules, they can be decomposed into stem + affix, and can thus prime their base stem directly. Irregular plurals and participles, however, access full-form entries stored in memory and cannot directly activate their corresponding base entries; therefore the priming route is less direct.

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Appendix A. Past participles

Morphologically related prime–target pairs used as experimental items in the participle condition:

A–B–A verbs	
gegraben (digged)	graben (dig)
geschlafen (slept)	schlafen (sleep)
geladen (loaded)	laden (load)
gelaufen (run)	laufen (run)
gerufen (called)	rufen (call)
gelassen (let)	lassen (let)
gehalten (held)	halten (hold)
gefressen (gorged)	fressen (gorge)
gewaschen (washed)	waschen (wash)
gegessen (eaten)	essen (eat)
gestoβen (pushed)	stoβen (push)
gelesen (read)	lesen (read)
geschlagen (beaten)	schlagen (beat)
gegeben (given)	geben (give)
gebraten (roasted)	braten (roast)
geblasen (blown)	blasen (blow)
geraten (guessed)	raten (guess)
gemessen (measured)	messen (measure)
gefangen (caught)	fangen (catch)
getreten (kicked)	treten (kick)
gesehen (seen)	sehen (see)

Morphologically related prime–target pairs used as experimental items in the participle condition:

Regular verbs	
gekriegt (get)	kriegen (get)
gesegnet (blessed)	segnen (bless)
geweint (cried)	weinen (cry)
gestartet (started)	starten (start)
gewarnt (warned)	warnen (warn)
geöffnet (opened)	öffnen (open)
gezeigt (showed)	zeigen (show)
gepackt (packed)	packen (pack)

(*continued*)

Regular verbs		
	geordnet (sorted)	ordnen (sort)
	gestürzt (fallen)	stürzen (fall)
	geleisted (achieved)	leisten (achieve)
	geleitet (led)	leiten (lead)
	gelernt (learned)	lernen (learn)
	gehandelt (acted)	handeln (act)
	geplant (planned)	planen (plan)
	geherrscht (ruled)	herrschen (rule)
	geprüft (tested)	prüfen (test)
	gehofft (hoped)	hoffen (hope)
	gekauft (bought)	kaufen (buy)
	gefolgt (followed)	folgen (follow)
	gerechnet (calculated)	rechnen (calculate)

Appendix B. Noun plurals

Morphologically related prime–target pairs used as experimental items in the plural condition:

-s plurals		
	Kolibris (hummingbirds)	Kolibri (hummingbird)
	Tombolas (lotteries)	Tombola (lottery)
	Gorillas (gorillas)	Gorilla (gorilla)
	Flamingos (flamingos)	Flamingo (flamingo)
	Lassos (lassos)	Lasso (lasso)
	Kartons (boxes)	Karton (box)
	Briketts (briquets)	Brikett (briquet)
	Festivals (festivals)	Festival (festival)
	Tips (hints)	Tip (hint)
	Zebras (zebras)	Zebra (zebra)
	Albinos (albinos)	Albino (albino)
	Lampions (lanterns)	Lampion (lantern)
	Fiaskos (failures)	Fiasko (failure)
	Ponys (ponys)	Pony (pony)
	Dias (slides)	Dia (slide)
	Salons (salons)	Salon (salon)
	Decks (decks)	Deck (deck)
	Apartments (flats)	Apartment (flat)

(*continued*)

-s plurals	
Studios (studios)	Studio (studio)
Kinos (cinemas)	Kino (cinema)
Embargos (embargos)	Embargo (embargo)
Pullis (sweaters)	Pulli (sweater)
Moskitos (mosquitos)	Moskito (mosquito)
Safaris (safaris)	Safari (safari)
Kobras (cobras)	Kobra (cobra)
Bonbons (sweets)	Bonbon (sweet)
Omas (grandmas)	Oma (grandma)
Kommandos (commands)	Kommando (command)
Details (details)	Detail (detail)
Echos (echos)	Echo (echo)

Morphologically related prime–target pairs used as experimental items in the plural condition:

-er plurals	
Blätter (leaves)	Blatt (leaf)
Altertümer (antiquities)	Altertum (antiquity)
Nester (nests)	Nest (nest)
Kälber (calves)	Kalb (calf)
Gewänder (robes)	Gewand (robe)
Denkmäler (monuments)	Denkmal (monument)
Rinder (cows)	Rind (cow)
Löcher (holes)	Loch (hole)
Bücher (books)	Buch (book)
Kinder (children)	Kind (child)
Lämmer (lambs)	Lamm (lamb)
Hölzer (woods)	Holz (wood)
Würmer (worms)	Wurm (worm)
Gemüter (minds)	Gemüt (mind)
Kräuter (herbs)	Kraut (herb)
Hühner (chicken)	Huhn (chicken)
Gräser (grasses)	Gras (grass)
Dächer (roofs)	Dach (roof)
Mitglieder (members)	Mitglied (member)
Bilder (pictures)	Bild (picture)
Räder (wheels)	Rad (wheel)
Sträucher (bushes)	Strauch (bush)
Körner (grains)	Korn (grain)

(*continued*)

-er plurals	
Gespenster (ghosts)	Gespenst (ghost)
Fässer (barrels)	Faβ (barrel)
Hörner (horns)	Horn (horn)
Reichtümer (riches)	Reichtum (riches)
Eier (eggs)	Ei (egg)
Ämter (offices)	Amt (office)
Männer (men)	Mann (man)

Appendix C. Diminutives

Morphologically related prime–target pairs used as experimental items in the diminutive condition:

With umlaut	
Strauch (bush)	Sträuchlein
Kalb (calf)	Kälbchen
Korn (grain)	Körnchen
Horn (horn)	Hörnchen
Rad (wheel)	Rädchen
Blatt (leaf)	Blättchen
Buch (book)	Büchlein
Mann (man)	Männchen
Dach (roof)	Dächlein
Tafel (blackboard)	Täfelchen
Glas (glass)	Gläschen
Faβ (barrel)	Fäβchen
Gras (grass)	Gräslein
Tuch (cloth)	Tüchlein
Holz (wood)	Hölzchen
Rand (border)	Rändchen
Haus (house)	Häuschen
Mauer (wall)	Mäuerchen
Stuhl (chair)	Stühlchen
Baum (tree)	Bäumchen
Lamm (lamb)	Lämmchen
Wurm (worm)	Würmchen
Kraut (herb)	Kräutlein
Huhn (chicken)	Hühnchen

(*continued*)

With umlaut	
Loch (hole)	Löchlein
Mund (mouth)	Mündchen
Dorf (village)	Dörfchen
Volk (nation)	Völkchen
Wald (forest)	Wäldchen
Arm (arm)	Ärmchen

Morphologically related prime–target pairs used as experimental items in the diminutive condition:

Without umlaut	
Kleid (dress)	Kleidchen
Licht (light)	Lichtchen
Kind (child)	Kindchen
Weib (woman)	Weibchen
Finger (finger)	Fingerchen
Pferd (horse)	Pferdchen
Stift (pen)	Stiftchen
Schirm (umbrella)	Schirmchen
Bein (leg)	Beinchen
Fleck (spot)	Fleckchen
Bild (picture)	Bildchen
Brett (board)	Brettchen
Gesicht (face)	Gesichtchen
Fisch (fish)	Fischlein
Heft (notebook)	Heftchen
Brief (letter)	Briefchen
Hemd (shirt)	Hemdchen
Kerl (fellow)	Kerlchen
Schwein (pig)	Schweinchen
Schlüssel (key)	Schlüsselchen
Schild (sign)	Schildchen
Nest (nest)	Nestchen
Ei (egg)	Eichen
Fenster (window)	Fensterchen
Bier (beer)	Bierchen
Film (film)	Filmchen
Stein (stone)	Steinchen
Spiel (game)	Spielchen
Tier (animal)	Tierchen

(*continued*)

Without umlaut		
	Schiff (ship)	Schiffchen

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