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**Priming Effects of German Participles - the Past-Tense Debate is not Over Yet**

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Abstract
We investigated whether German regular and irregular participles are accessed via parsing or retrieval from lexical memory, and whether such processes are handled by a single or a dual system. In particular, we tested whether the assumptions of the “dual-mechanism” account—that regular participles are parsed whereas irregular participles are retrieved as whole words—can be maintained. German participle formation is of particular interest, since it is concatenative for both regular and irregular participles, and results from combinations of regular/irregular stems with regular/irregular suffixes. Two priming experiments (cross-modal and visual) compared the patterns of identity priming, *kaufe* (buy) – *kaufe*, and participle priming, *gekauft* (bought) – *kaufe*, for regular verbs and two types of irregular verbs. Results showed similar priming patterns throughout for regular and irregular verbs. When priming patterns for regular and irregular verbs did differ, this reflected differences in surface frequency. These data support a single system that processes and decomposes both regular and irregular German inflection.

**Keywords:** morphology, inflectional morphology, repetition priming, participle priming, morphological decomposition, lexical retrieval
Words have a double nature: they appear as elementary units of speech and language, and they often display internal complexity, a property caused by the inflectional, derivational and compounding morphology of words. It is therefore no surprise that both properties, divisibility and indivisibility, must be represented in models of word processing, and that the precise division of labor between storage and analysis of words has been a contentious issue between advocates of different approaches. Among the classes of words which have been studied thoroughly from this perspective are the various forms of English and German verbs (see references below).

Although protagonists of competing positions may have become somewhat wary, the past-tense debate is not over yet. Past participle forms (as well as past-tense forms) have been used to investigate the organization of the mental lexicon in the search for answers to the following questions. First, are participles accessed via their morphemic constituents, or are they retrieved as whole-word units from memory? Second, are regular and irregular participles handled by different processes? That is, are regular forms processed via parsing, whereas irregular forms are retrieved as whole-word units from memory? Third, if so, are the parsing and retrieval processes handled by a single or by a dual system?

Since there are so many models of the structure of the mental lexicon, in the following we selectively consider only a few exemplary models that particularly deal with the processing of regular and irregular past-tense or participle formation. In doing so, however, we also need to take into account cross-linguistic differences in the nature of irregularity – focusing here on English and German. The Past-Tense Debate was originally developed in the context of English, where the regularity/irregularity distinction brings with it an additional distinction in terms of morpho-phonological decomposability (Marslen-Wilson &
Tyler, 1998). All English regular past-tense forms have a transparent \{stem\} + \{affix\} surface form, as in strings like *jumped* (\{jump\} + \{-ed\}) or *greeted* (\{greet\} + \{-ed\}).

Irregular past tense forms, like *gave*, *bought*, or *took*, typically are not morpho-phonologically decomposable into a stem and an inflectional affix, and must enter into the access process as unanalysable whole forms. In German, however – as discussed in more detail below – both regular participles, such as *gekauft* (bought), and irregular participles such as *gesoffen* (boozed), share a morpho-phonologically decomposable surface organization. In particular, both regular and irregular forms begin and end with readily identifiable inflectional affixes – \{ge-\} and \{-t\} or \{-en\} in the examples given. This means that parsing processes can be applied, at least in principle, equally effectively to both regular and irregular forms.

Bearing these cross-linguistic contrasts in mind, we now turn to the different types of model that have been proposed. First, there are single-system/single-process models that assume whole-form memory retrieval for both regular and irregular forms. These are exemplified by connectionist network models (e.g., Joanisse & Seidenberg, 1999; Plaut & Gonnerman, 2000; Rueckl, Mikolinski, Raveh, Miner, & Mars, 1997; Smith, 1995), which implement an associative memory system that computes meaning representations from orthographic or phonological representations. These form-to-meaning mappings encode regularities associated with morphological relationships, but without explicit morphological representations, so that the meaning representations of regular and irregular past-tense forms are computed by the same process and within the same system. This approach will treat English and German regular and irregular forms in the same manner, with any differences reflecting variations in phonological predictability but not in the nature of the underlying representations or access processes.
A second type of single-process model assumes parsing for both regular and irregular forms, as proposed by Smolka, Zwitserlood, and Rössler (2007). This resembles connectionist models in that it assumes a single system handling the same process for both regular and irregular participles. It differs from connectionist models in that the form-to-meaning mappings are abstracted into morphological representations, such that all forms are accessed via their constituent morphemes. As we noted above, this type of model is well adapted to languages like German, predicting no intrinsic difference between regular and irregular participles.

A third type of model, labelled single-system/dual process, assumes that both types of processing, parsing and retrieval, operate consecutively or in parallel within a single system. For example, morpheme-first models assume that all complex forms are parsed into separate morphemic units before whole-word representations can be accessed (Taft, 1979, 2004; Taft & Forster, 1975). In this model, regular past-tense forms are parsed into their constituent morphemes at an early processing stage, whereas irregular past-tense forms are accessed as whole-word units at a later processing stage. In the dual-route model of Schreuder and Baayen (1995), morphemic constituents and whole word units are stored at the same level, so that parsing for regular forms and retrieval for irregular verb forms run in parallel within the same system. In this model, frequency is a crucial factor that determines whether words are parsed or retrieved. High-frequency regular forms will also develop a whole word representation, and will thus be retrieved as well. Such models are in principle adaptable to both German and English variants of the regularity/irregularity distinction.

The fourth type of model, labeled dual-system/dual-process, assumes two distinct systems, one that parses regular forms into their constituent morphemes, and another one that retrieves irregular forms from memory as undecomposed whole forms (e.g., Clahsen, 1999; Pinker, 1998; Pinker & Ullman, 2002; Prasada & Pinker, 1993; Ullman, 2001). The linguistic
basis for dual-system approaches is provided by Chomsky’s (1970) lexicalist hypothesis, where universal and language-specific (phrase structure and transformational) rules are distinguished from a lexicon. This hypothesis is implemented in so called “dual-mechanism” approaches that postulate two independent and innate systems: the system that is governed by default rules, and another that acquires and stores all exceptions to the default rules. A major assumption of dual-mechanism models is that regular and irregular verbs are processed by these distinct systems—regular verbs by the default system and irregular verbs by the memory system. Hence, the different processing characteristics of the two systems should be reflected in different performance patterns between regular and irregular verbs. This is argued to apply to both English and to German types of irregularity – since non-default forms are always stored as full forms, it is irrelevant whether or not they are potentially parsable.

Another dual-system/dual-process type of model developed by Marslen-Wilson, Tyler, and colleagues (e.g., Marslen-Wilson & Tyler, 1998, 2007) places the “past-tense debate” in a broader neuro-biological context, arguing that a specific left hemisphere neural system supports processes to do with regular inflectional morphology, while whole form and stem-based access processes have a broader bi-hemispheric substrate. This is structurally similar to the previous model in assuming two distinct (though interdependent) systems, but does not specify how inputs will map onto these two systems in terms of regularity or irregularity per se, but rather in terms of the presence or absence of overt inflectional morphemes. On this account, English regulars and irregulars will be processed differently, because the irregular forms are not morpho-phonologically complex. German regulars and irregulars should not, however, be processed qualitatively differently, because they are both decomposable into stems plus inflectional affixes. These inflectional affixes should, on the Marslen-Wilson and Tyler (2007) model, obligatorily engage the same specialized left
hemisphere systems supporting the analysis of morpho-phonologically complex inflected forms (see also Post, Marslen-Wilson, Randall, & Tyler, 2008).

*Previous research: English regulars and irregulars*

Early evidence for processing differences between regular and irregular verbs focused entirely on English, as in the morphological priming study by Stanners, Neiser, Hernon, and Hall (1979). They used a long-lag repetition priming paradigm and compared the influence of inflectional and derivational variations of a verb on its uninflected stem. Regular past-tense forms (*poured*) primed their stems (*pour*) to the same extent as identical primes (*pour*). Stems of irregular verbs, such as *bend*, were also primed by their own past tense (*bent*), but to a lesser extent than by an identical prime. The same held for past-tense forms that shared fewer letters with their targets, such as *shook* priming *shake*. Derivational primes (which generally retain a stem + affix structure) also facilitated responses to their stems, but to a lesser extent than in identity priming, be it with regular stems as in *predictable* priming *predict* or with irregular/allomorphic stems as in *retention* priming *retain*.

Stanners et al. (1979) drew a distinction between *full* and *partial* activation that a stem may receive, and inferred two different systems. In the first system, only the stem has a lexical entry, which is shared by all other regularly inflected forms. Prior to memory access, the inflected forms are partitioned into suffix and stem, so that only the stem is accessed. This produces full activation of the stem when a regularly inflected form is encountered. The second system comprises separate lexical entries for irregularly inflected forms, and for derivations. These are tightly connected with their respective stem, thus producing partial activation of irregular stems when the past-tense form is accessed.

Subsequent studies tested these claims for full and partial priming for regular and irregular English verb inflections, with mixed results. Regularly inflected English verbs usually induced full priming of their stems (Fowler, Napps, & Feldman, 1985, Exp. 1;
Marslen-Wilson, 1999; Napps, 1989, Exp. 1; Napps & Fowler, 1987, Exp. 1), though partial priming was also found (Fowler et al., 1985, Exp. 2). The picture was less consistent for English irregular verbs, for prime/target pairs such as *gave/give*: different studies reported full priming (Forster, Davis, Schoknecht, & Carter, 1987, Exp. 7), partial priming (Napps, 1989, Exp. 2), and no priming at all (Marslen-Wilson, 1999). However, these studies employed very different priming techniques, including long-lag repetition priming, masked priming, and immediate repetition priming with overt primes using either cross-modal, auditory, or visual stimulus presentation. These techniques are known to produce different priming effects for the same prime-target pairs.

The interpretation of the presence or absence of full or partial priming, in terms of its implications for the effects of regularity, is complicated in English – as laid out above – by the confound between regularity and morpho-phonological decomposability. The German participle system, as we describe below, is not affected by this (and other confounds), and provides a more controlled environment for distinguishing between the different model classes.

**German regular and irregular participle formation**

German participle formation makes it possible to disentangle suffixation and stem preservation. An important feature of German participle formation is that both regular and irregular verbs undergo concatenative affixation processes. That is, the prefix *ge-* is attached to a stem, followed by one of two suffixes, *-t* or *-en*.

The prefix *ge-* is used for both regular and irregular participle formation. Its distribution is, without exception, prosodically conditioned (*ge-* must occur if the first syllable of a stem carries the main stress, see Wiese, 1996b), which is the reason why it is not focused upon here. With regard to the stem, the participle either preserves the infinitive stem, as in *gelaufen* (run) from *laufen* (run), or changes the stressed stem vowel. Most of these
vowel changes, sometimes accompanied by a consonant change, occur via Ablaut, as in
*gesoffen* (boozed) from *saufen* (booze; for a description of vowel changes see Wiese, 1996a).
Moreover, either the -t or the -en suffix is attached to the stem. Since both suffixes (-t/-en)
combine with both stems (infinitive/vowel change), all possible stem and suffix combinations
are found in German (see Table 1).

Table 1 about here

Even though all stem/suffix combinations exist in German, their type and token
frequencies are extremely skewed.² The CELEX data base (Baayen, Piepenbrock, & Van
Rijn, 1993) counts roughly 1900 monomorphemic German verbs. Of these, about 1700
combine the infinitival stem and the -t suffix, whereas less than 200 verbs cover the other
three stem and suffix combinations. Since the infinitival stem is of higher type frequency than
a stem with vowel change, and the -t suffix is more frequent than the -en suffix, we label the
type that combines the frequent stem and the frequent suffix as ‘regular’, and the other
combinations as ‘irregular 1’, ‘irregular 2’, and ‘irregular 3’ according to the labels used in
Smolka et al. (2007). This assignment of the label ‘regular’, although made on different
grounds, is consistent with classic dual-mechanism accounts (Clahsen, 1999; Marcus,
Brinkmann, Clahsen, Wiese, & Pinker, 1995; Sonnenstuhl, Eisenbeiss, & Clahsen, 1999;
Wunderlich & Fabri, 1995). These authors consider the combination of the infinitive stem
with the -t suffix as the default combination, since it is productive and applied in ‘elsewhere’
conditions, which is also reflected in its high type frequency: New verbs like *simsen* (send an
SMS), denominal verbs like *ruhen* (rest, v.) from *Ruhe* (rest, n.), and derived verbs like
*archivieren* (archive, v.) from *Archiv* (archive, n.) are formed productively in this group.
Moreover, low-frequency irregular participles such as *gequollen* (welled) are regularized into
this class, resulting in *gequellt*. Table 1 provides the different stem/suffix combinations together with their labels and details about type and token frequencies.

An important characteristic of German participle formation (as in English) is that the surface form of a verb does not predict its inflection type. That is, the phonological features of onset or rhyme do not determine whether a stem vowel is changed or not, and whether -t or -en is suffixed. For example, verbs with similar stem rhymes like *kaufen* (buy), *laufen* (run), and *saufen* (booze) may belong to different verb regularities, as Table 1 shows.

To summarize, the affixation process of German participle formation is highly constrained: the prefix *ge-* and one of two suffixes, -t or -en, are affixed to the stem. However, it is completely unpredictable whether a given stem undergoes vowel change or not and which of the two suffixes is attached to the stem.

Within the domain of repetition-priming studies, only one published experiment has examined regular and irregular participles in German. Using cross-modal priming, Sonnenstuhl et al. (1999) compared ‘regular’ and ‘irregular 1’ verbs, which both keep the infinitival stem unchanged. Targets were inflected verbs in the first person singular present (stem + -e suffix; e.g., *kaufe*, buy). These were preceded either by themselves (identity priming; *kaufe*), by their participle form (participle priming; *gekauft*, bought), or by an unrelated verb that was also in the first person singular present (*zeichne*, draw). Identical and participle primes produced equal priming if the verbs were of the regular type, but not if they were of the irregular type. Following the logic of Stanners et al. (1979), the authors concluded that the full priming for regular verbs indicated that their stems are directly accessed by all inflected forms. In contrast, partial priming effects for irregular participles were interpreted as evidence for separate lexical entries of the morphological variants. These priming differences were further taken as evidence for radically different processing systems,
namely a default system that generates regular participles from stems, and a memory system that stores the whole-word forms of irregular participles.

However, a closer look at their results (see Table 2 in Sonnenstuhl et al., 1999) shows that the participle priming by ‘irregular 1’ verbs (25 ms) was equivalent to that by ‘regular’ verbs (30 ms). The critical interaction is in fact driven by stronger identity priming for ‘irregular 1’ verbs (57 ms) than for ‘regular’ verbs (30 ms). Sonnenstuhl et al. (1999) did not, however, discuss why identity priming was so different for their ‘regular’ and ‘irregular’ verbs. Smolka et al. (2007) have recently argued that this may have resulted from frequency differences, with ‘irregular 1’ verbs being of higher frequency than ‘regular’ verbs. The critical interaction may be a confound of frequency rather than reflecting the operations of two different processing systems.

Nevertheless, and even though it is a single experiment, these results—full priming for regular in contrast to partial priming for irregular German participles—have become a cornerstone of the dual-mechanism account with regard to verb inflection, and have been often cited in the linguistic, psycholinguistic and neuropsychological domains, in studies with behavioral, event-related-potential, acquisition, and patient data. It is therefore important to assess whether these findings can be replicated, and to examine whether some additional implicit hypotheses of the dual-mechanism model can be verified.

These were the aims of the following two experiments. Experiment 1 contrasted participle and identity priming of ‘regular’, ‘irregular 1’, and ‘irregular 2’ verbs in the cross-modal domain. Experiment 2 compared participle and identity priming of ‘regular’ and ‘irregular 2’ verbs in the visual domain at three different stimulus onset asynchronies (SOA). To anticipate the results, both experiments failed to replicate the findings of Sonnenstuhl et al. (1999) and revealed that priming patterns did not depend on verb regularity. The detailed issues will be spelled out below, where relevant for each experiment.
Experiment 1

Experiment 1 was conducted to replicate the design of the original Sonnenstuhl et al. (1999) study as closely as possible: we applied cross-modal repetition priming, used similar items as in the original study, with all targets in first-person singular, and included large amounts of fillers to reduce the relatedness proportion.

In addition to the contrast of ‘regular’ and irregular 1’ participles, where both particle types maintain the infinitive stem and differ only in the suffix, we included also ‘irregular 2’ verbs. Dual-mechanism models maintain a dichotomous differentiation between a regular system and an irregular system—indeed, independent of the “amount of irregularity”. Some more recent proponents suggested that the regularity of the suffix determines the parsing processes (e.g., Clahsen, Prüfert, Eisenbeiss, & Cholin, 2002). Participles with the regular -t suffix are parsed, and the priming of regular participles relies on the activation of the same stem. In contrast, since ‘irregular 1’ and ‘irregular 2’ participles do not take the ‘regular’ -t suffix, these forms are expected to be retrieved as whole units, so that the priming of irregular participles relies on the activation of related entries in a semantic network. This dual-mechanism argument thus predicts an interaction between verb regularity and priming pattern, that is, ‘regular’ participles should yield full priming, whereas ‘irregular 1’ and ‘irregular 2’ participles should produce partial priming. By comparing all three possibilities along the gradient of verb regularity, we asked whether a strict dichotomy between regular and irregular verbs exists. This would mean that, when compared to regulars, different subgroups of irregulars should behave like a homogeneous group.

In addition, Experiment 1 tested another hypothesis of the dual-mechanism account. The dual-mechanism account assumes that the default system comprises only the stems of regularly inflected verbs. This processing system should thus be affected by stem frequencies, but not by the surface frequencies of inflected forms, such as the surface frequency of
participles. Hence, a second major assumption of the dual-mechanism model is that surface frequency should not affect regularly inflected forms (Clahsen, 1999). In contrast, another single-system/dual-process model has shown that even regular words may be stored if they are of high frequency (Baayen, Dijkstra, & Schreuder, 1997; Schreuder & Baayen, 1995). Experiment 1 thus examined whether ‘regular’ verbs are affected by surface frequencies when base frequencies are kept constant.

Method

Participants

Fifty-three students of Münster University took part in the experiment. They received course credits or payment for their participation. All participants were native speakers of German and had normal hearing, and normal or corrected-to-normal vision.

Materials

Word stimuli. The critical materials consisted of 90 German verbs, with 30 verbs of the ‘regular’ type, 30 verbs of the ‘irregular 1’, and 30 verbs of the ‘irregular 2’ type (for stem/suffix combinations see Table 1).

As in the experiment of Sonnenstuhl et al. (1999), all target verbs were presented in the first-person singular present inflection (stem + -e suffix). Each visual target was combined with three spoken primes: (a) the identical word form, also in the first-person singular, (b), the past participle of the target verb, and (c) an unrelated verb, also in the first-person singular. All stimuli are listed in Appendix B.

Materials were closely matched for length and frequency (from the CELEX data base, Baayen et al., 1993). The mean surface frequency for targets (and their identical primes) was 6.9 for ‘regular’ verbs, 7.6 for ‘irregular 1’ verbs, and 7.2 for ‘irregular 2’ verbs. Past-
participle frequency was higher overall, but again similar across the verb sets: 41.9 for ‘regular’, 29.1 for ‘irregular 1’, and 35.6 for ‘irregular 2’ verbs. The mean lemma frequencies were also closely matched, with 246 for ‘regular’, 247 for ‘irregular 1’, and 245 for ‘irregular 2’ verbs. Finally, control primes were matched in frequency to the identical primes from the same verb set: 7.2, 6.9, and 7.3 for ‘regular’, ‘irregular 1’, and ‘irregular 2’ verbs, respectively.

Although the complete set of 30 ‘regular’ verbs was fully matched for mean lemma and first-person singular frequency to the other two sets, it contained two subsets of 15 verbs each, which differed only with respect to mean participle frequency (57.4 per million in the High set, vs. 26.4 in the Low set). The mean participle frequency in the Low set is comparable to that of the regular-verb participles in Sonnenstuhl et al. (1999; see Footnote 3).

**Filler items.** A large number of fillers were included to conceal the make-up of the test materials. First, the relatedness proportion was reduced from 67% to 25%, by adding 150 unrelated word-word fillers. Similar to the test stimuli, two-thirds had first-person singular primes, one third participle primes. To obscure the fact that all test targets were in the first-person singular inflection, 60 fillers had either third-person singular or participle targets. Moreover, 90 fillers had derived targets, either derived nouns (e.g., *Klugheit*, wisdom) or adjectives (e.g., *weltlich*, worldly).

**Pseudoword stimuli.** For the lexical decision task, 240 word-pseudoword prime-target pairs were constructed, modeled after the test and filler trials, with targets resembling first or third-person singular verbs (e.g., *bilge*, *hankelt*), past participles (e.g., *gelunden*) or derived words (e.g., *Gemümpel*, *draulich*). Word primes and pseudoword targets were form-related in 60 of the 240 trials (e.g., *geschlafen* - *schlufe*).
**Apparatus**

All primes were recorded onto DAT tape by a female native speaker of German, within one recording session, using a Sennheiser HME 25 microphone. The primes were digitally stored, their onset and offset was marked under auditory and visual control, using X-Waves software. Each prime was stored as a separate digital wav-file. Visual target stimuli were presented on a 15” monitor (Sony Multiscan), connected to an IBM-compatible PC. Presentation and timing of stimuli was controlled by NESU software (Wittenburg, Nagengast, & Baumann, 1998). Responses were registered by a push button box.

**Procedure**

The materials were distributed over three lists by means of a Latin-square design, such that each target occurred only once per list, with a different prime on each list. Each list contained ten items in each prime condition of each verb regularity, and fillers were the same on each list. Four random orders were created for each list. A separate set of 22 trials, modeled after test and filler items, was used as practice material.

Participants received a written instruction, with examples of words (verb forms and derived words) and pseudowords, and were tested in groups up to four. Primes were presented auditorily, target words were presented visually. Each trial started with a warning sign (an *), presented in the middle of the screen for 250 ms. After 200 ms, the spoken prime word was played over closed headphones. Immediately after the offset of the spoken prime (ISI=0), the visual target word was presented centred on the screen, white on black in uppercase letters, for the duration of 400 ms.

Participants made lexical decisions to the targets, by pressing one of two buttons. Word decisions were always made with the dominant hand. The time-out period was set to 1500 ms after target offset. After timeout, the next trial started, again preceded by a warning
sign. There was short break halfway through the session. The experiment lasted about 35 minutes.

**Results**

Four items that had been incorrectly coded and three items that were incorrectly classified as pseudowords by more than one third of the participants in a cell were removed. Five participants whose error mean deviated more than three standard deviations from the group mean were removed, so that 48 participants were included in the data analyses. Mean response latencies were calculated for correct responses; mean error rate was 3.4%. Means over word and nonword responses were calculated separately for each participant, and reaction times (RTs) exceeding three standard deviations from a participant’s mean were excluded. There was no speed-accuracy trade-off (RT and error means over participants were not correlated, $r = -0.03132$, $p = .5161$).

Analyses were performed on response latency and accuracy data, with participants ($F_1$) and items ($F_2$) as random variables. In the following analyses by participants ($F_1$), all variables were treated as repeated-measures factors; in the analyses by items ($F_2$), Regularity and Frequency were between-items factors and Prime Type was a repeated-measures factor. Table 2 provides the RT and error means; the right panel of Figure 1 depicts the priming effects (RT unrelated prime – RT test prime). All priming effects were significantly different from zero.

| Table 2 about here |

The aim of Experiment 1 was to examine whether regular participles induce full priming, whereas irregular participles induce partial priming. For this purpose, priming
effects for response latencies and accuracies were entered in 3 x 2 ANOVAs with Regularity
(‘regular’/‘irregular 1’/‘irregular 2’) and Prime Type (identity/participle) as factors. There
were no significant effects in the accuracy data.

On latencies, the main effect of Prime Type was highly significant, $F_1(1, 47) = 37.66,$
$p < .0001; F_2(1, 80) = 35.98, p < .0001$. Identity priming (56 ms) was stronger than participle
priming (26 ms). The main effect of Regularity was significant by participants, $F_1(2, 94) =
3.79, p = .0261; F_2(2, 80) = 2.40, p = .0976$. A post-hoc comparison (Newman-Keuls)
confirmed that ‘irregular 1’ verbs (54 ms) yielded most priming, and stronger priming than
either ‘regular’ (32 ms) or ‘irregular 2’ verbs (37 ms), whereas the amount of priming did not
differ between the latter two verb types.

Most importantly, the interaction between Regularity and Prime Type was not
significant ($F_1$ and $F_2 < 1$). In addition, a one-way ANOVA for each verb type separately
confirmed that participle priming was partial. For ‘regular’ verbs, participle priming (21 ms)
was significantly weaker than identity priming (42 ms), $F_1(1, 47) = 23.82, p < .0001; F_2(1,
29) = 4.58, p = .0409$. The same held for ‘irregular 1’ participles (38 ms) and the
corresponding identity primes (69 ms), $F_1(1, 47) = 11.03, p = .0017; F_2(1, 26) = 17.44, p =
.0003. For ‘irregular 2’ verbs, participles (20 ms) also primed to a lesser extent than the
identical word forms (55 ms), $F_1(1, 47) = 19.66, p < .0001; F_2(1, 25) = 29.28, p < .0001$.

Post-hoc comparisons (Newman-Keuls) did not reveal any significant differences
between the priming effects induced by participles (21 ms for ‘regular’ participles, 20 ms for
‘irregular 2’ and 38 ms for ‘irregular 1’ participles). In contrast, identity priming effects
differed: Priming was significantly stronger for ‘irregular 1’ verbs (69 ms) than for ‘regular’
verbs (42 ms), whereas the effect of ‘irregular 2’ verbs (55 ms) did not differ from the other
two conditions.
To examine whether surface frequency affects priming for ‘regular’ verb forms, we ran one-way ANOVAs with ‘Participle Frequency’ (high/low) and Prime Type (identity/participle) on the data for ‘regular’ verbs. The main effect of Participle Frequency was significant, $F_1(1, 47) = 10.94, p = .0018; F_2(1, 28) = 4.99, p = .0337$, as was the main effect of Prime, $F_1(1, 47) = 24.41, p < .0001; F_2(1, 28) = 4.69, p = .0390$. Interestingly, the interaction was significant, though only with the analysis by participants, $F_1(1, 47) = 4.59, p = .0373; F_2(1, 28) = 1.68, p = .2059$. Planned comparisons showed that for high-frequency participles, identity priming (31 ms) was significantly different from participle priming (-4 ms), $F_1(1, 47) = 19.18, p < .0001; F_2(1, 14) = 3.91, p = .0680$. In contrast, low-frequency participles, with similar frequencies as in Sonnenstuhl et al. (1999), produced the same amount of priming (45 ms) than corresponding identity primes (54 ms): $F_1(1, 47) = 1.89, p = .1762; F_2 < 1$.

When only the low-frequency set was included as ‘regular’ verb set, we replicated the results of Sonnenstuhl et al. (1999), in 2 x 2 ANOVAs with Regularity (‘regular’/‘irregular 1’) and Prime Type (identity/participle) as factors. The main effect of Regularity was not significant ($F_1$ and $F_2 < 1$). As in all other analyses, the main effect of Prime Type was significant, $F_1(1, 47) = 12.88, p = .0008; F_2(1, 40) = 15.28, p = .0003$. Most importantly, the interaction reached significance, $F_1(1, 47) = 3.27, p = .0770; F_2(1, 40) = 3.29, p = .0772$. This interaction, together with the interaction for the original data by Sonnenstuhl et al. (1999) is illustrated in Figure 2.

Figure 2 about here
Discussion

The results of Experiment 1 were straightforward: All verb regularities - regular’, ‘irregular 1’, and ‘irregular 2’ participles - produced partial priming, without any interaction between verb type and priming pattern. This contrasts with the results of Sonnenstuhl et al. (1999) who found full priming for ‘regular’ participles and partial priming for ‘irregular 1’ participles.

Our experiment was closely modeled after the original Sonnenstuhl (1999) study: it was conducted with cross-modal presentation, with the same type of target inflection, large amount of fillers, and indeed shared many of the same materials - taking 21 ‘irregular 1’ verbs and seven out of the 21 ‘regular’ verbs from the Sonnenstuhl study. Notwithstanding these parallels, we did not replicate their critical interaction - full priming for ‘regular’ versus partial priming for ‘irregular 1’ participles. However, we did find effects of surface frequency of the ‘regular’ participles. We replicated their critical interaction, showing that the identity priming of ‘irregular 1’ verbs exceeds that of ‘regular’ verbs. Note that this interaction, which was interpreted in terms of full and partial priming, shows differences in identical priming rather than in participle priming between ‘regular’ and ‘irregular’ verbs. We discuss these findings in detail in the general discussion below.

Experiment 2

Experiment 2 aimed at replicating the findings of Sonnenstuhl et al. (1999), who applied a cross-modal priming paradigm, in the visual modality. Cross-modal and visual stimulus presentations are known to influence morphological processing in different ways (e.g., Feldman & Larabee, 2001), and might tap into different levels of representation: amodal representations with cross-modal presentation, more access-near representations with visual presentation (cf. Marslen-Wilson, Tyler, Waksler, & Older, 1994). To track the time
course of effects, we varied the timing of visual stimulus presentation, using three different SOAs: 90 ms, 200 ms, and 600 ms. Semantic influences on morphological processing seem to depend on the processing time of the prime (e.g., Feldman & Prostko, 2002; Rastle, Davis, Marslen-Wilson, & Tyler, 2000), and shorter SOAs should reduce the possibility of tapping into semantic effects only.

In Experiment 2, we compared ‘regular’ and ‘irregular 2’ participles, which differ on two dimensions: stem and suffix formation. We reasoned that this should maximize the options for a differentiation between regular and irregular forms. We used the same priming conditions as Sonnenstuhl et al. (1999), in order to measure full and partial participle priming. Targets were preceded either by themselves (identity prime), by their own participle (participle prime), or by an unrelated verb with the same inflection as the target (unrelated prime). Again, according to the dual-mechanism account, we expected the following interaction between verb regularity and priming pattern: ‘regular’ participles should yield full priming, whereas ‘irregular 2’ participles should produce partial priming.

Method

Participants

Eighty-eight Marburg university students participated in the experiment; 32 in ‘SOA 600’, 25 in ‘SOA 200’, and 31 in ‘SOA 90’. Participants received course credit or payment. All were monolingual native speakers of German. They were not dyslexic and had normal or corrected-to-normal vision.

Materials

Word stimuli. Sixty German monomorphemic verbs were used, 30 verbs of the ‘regular’ type with infinitive stem and -t suffix in the participle form, and 30 verbs of the
'irregular 2' type with infinitive stem and -en suffix (see Table 1). Frequency was matched according to the CELEX database (Baayen et al., 1993). The mean participle surface frequency (PF) was 39.1 per million for ‘regular’ verbs, and 44.8 per million for ‘irregular 2’ verbs. In order to avoid any confusion with the participle prefix ge-, no verb was allowed to begin with the letter combination ge- in the infinitive, as in geniessen (enjoy).

Half of the regular and irregular target verbs were presented in the first person (stem + -e suffix), the other half in the second person (stem + -st suffix). Many verbs in the first person are homographs to high-frequency nouns or adjectives, such as folge (I follow) versus Folge (sequence, n.) or stelle (I put) versus Stelle (position, n.). To avoid ambiguity, potential homographs to nouns were always shown in the second person (e.g., folgst, stellst), as the -st suffix does not occur in noun inflection.

The 60 verb targets were combined with three types of primes: (a) the identical word form, (b) the past participle of the target verb, and (c) an unrelated verb. The unrelated verbs preceding the target in the control condition had the same number of syllables and the same inflection as the target word. All were of the regular type, and orthographically and phonologically dissimilar to the target. The mean lemma frequencies of the control primes for ‘regular’ and ‘irregular 2’ targets were matched between the two sets (39.5 and 31 per million for ‘regular’ and ‘irregular 2’ verb targets, respectively). All verb stimuli are given in Appendix A.

Pseudoword stimuli. Sixty prime-target pairs with words as primes and pseudoverbs as targets were included. Pseudoverb targets were constructed by exchanging one or two letters in real verbs, while preserving the phonotactic constraints of German. As with verb targets, half of the pseudoverb targets were presented in the first person inflection (e.g., *lehfe), the other half in the second person inflection (e.g., *saulst).
Half of the pseudoverb targets were primed by ‘regular’ verbs, half by ‘irregular 2’ verbs, matched for frequency. The prime verbs were in all aspects closely modeled after the test conditions.

**Apparatus**

Stimuli were presented on a 15” monitor, connected to an IBM-compatible Intel 486 personal computer. Presentation and timing of stimuli was controlled by NESU software (Wittenburg et al., 1998). Responses were registered by a push button box.

**Procedure**

The 60 material sets with word targets were rotated over three experimental lists in a Latin square design. They were supplemented by the 60 prime-pseudoverb target pairs, which were identical for all three lists. Each list therefore included in total 120 prime-target pairs. Participants were randomly assigned to a list. They were tested individually in a dimly lit room, with a viewing distance of about 60 cm from the screen. Four prime-target pairs were used as demonstration trials, and participants were given 30 practice trials prior to the experimental session.

SOA was a between-subjects variable (cf. Napps & Fowler, 1987). Each trial started with the presentation of a fixation cross in the center of the screen for 1000 ms. The prime was then presented for 500 ms in the ‘SOA 600’ condition, and for 100 ms in the ‘SOA 200’ condition, both followed by 100 ms blank screen before the target appeared. In the ‘SOA 90’ condition’, the prime appeared for 40 ms, followed by 50 ms blank screen. Targets were presented for 160 ms in all conditions, followed by a blank screen. The intertrial interval was 4000 ms.

Stimuli were presented in white Sans Serif letters, size 20, on a black background; primes and targets were presented in the center of the screen.
Participants made lexical decisions to the target items, and were instructed to respond as fast and as accurately as possible. ‘Word’ responses were given with the index finger of the dominant hand, ‘pseudoword’ responses with the subordinate hand.

**Results**

Five items that were incorrectly classified as pseudowords by more than one-third of the participants were removed. This concerned two items in ‘SOA 90’ and ‘SOA 600’, and one item in ‘SOA 200’. Five participants whose RT mean or error mean deviated more than three standard deviations from the group mean were removed, so that 83 participants were included in the data analyses (30 participants in ‘SOA 600’, 24 in ‘SOA 200’, and 29 in ‘SOA 90’). Means over word and nonword responses were calculated separately for each participant, and reaction times (RTs) exceeding three standard deviations from a participant’s mean were excluded. Mean error rates were 2.7% in ‘SOA 600’, 3.9% in ‘SOA 200’, and 2.8% in ‘SOA 90’. There was no speed-accuracy trade-off (RT and error means over participants were positively correlated, $r = .07166$, $p = .0237$).

Analyses were performed on response latency and accuracy data, with participants ($F_1$) and items ($F_2$) as random variables. In the analyses by participants ($F_1$), SOA was treated as between-subjects factor, and Regularity and Prime Type were repeated-measures factors; in the analyses by items ($F_2$), Regularity was a between-items factor, and SOA and Prime Type were repeated-measures factors. Table 3 provides the RT and error means; the left panel of Figure 1 depicts the effects of ‘participle priming’ (RT unrelated prime – RT participle prime) and ‘identity priming’ (RT unrelated prime – RT identity prime). All priming effects were significantly different from zero.

__________________________
Table 3 and Figure 1 about here__________________________
Experiment 2 examined whether regular participles induce full priming, whereas irregular participles induce partial priming. The priming effects for response latencies and accuracies were entered in a 3 x 2 x 2 analyses of variance (ANOVA) with factors SOA (90/200/600), Regularity (‘regular’/‘irregular 2’), and Prime Type (identity/participle). Besides a single interaction (see below), there were no significant effects with the accuracy data.

On latencies, the main effect of Regularity was not significant, $F_1(1, 80) = 1.74, p = .1914; F_2 < 1$. Most importantly, none of the interactions with Regularity were significant on any measure: Regularity x SOA ($F_1$ and $F_2 < 1$); Regularity x Prime Type, $F_1(1, 80) = 1.52, p = .2219; F_2 < 1$; Regularity x Prime Type x SOA ($F_1$ and $F_2 < 1$). This lack of regularity effects confirms that, overall, ‘regular’ verbs (63 ms) were primed to the same extent as ‘irregular’ verbs (54 ms), indicating that there is no general difference between ‘regular’ and ‘irregular 2’ verbs.

In contrast, the main effect of Prime Type was highly significant, $F_1(1, 80) = 104.61, p < .0001; F_2(1, 55) = 78.79, p < .0001$. Priming was stronger when verb targets were preceded by identical primes (82 ms) than by participle primes (35 ms). The main effect of SOA was also significant, $F_1(2, 80) = 11.15, p < .0001; F_2(2, 110) = 5.05, p = .0080$, indicating that the priming effects increased with longer SOAs (SOA 90: 34 ms, SOA 200: 62 ms, SOA 600: 78 ms). The interaction between Prime Type and SOA was significant on the latency data, $F_1(2, 80) = 8.38, p = .0005; F_2(2, 110) = 5.64, p = .0047$, as well as on the accuracy data, $F_1(2, 80) = 3.66, p = .0302; F_2(2, 110) = 4.85, p = .0096$. Longer SOAs amplified the amount of priming, however, the increase was stronger for identity priming (SOA 90: 46 ms, 0.6%; SOA 200: 88 ms, 3.8%; SOA 600: 112 ms, 2.6%) than for participle priming (SOA 90: 23 ms, 1.1%; SOA 200: 37 ms, 1.9%; SOA 600: 45 ms, 2.1%).
Even though the three-way interaction Regularity x Prime x SOA was not significant, we wanted to make sure that Regularity did not interact with Prime type at any of the different SOA levels. We conducted 2 x 2 ANOVAs with Regularity and Prime Type separately for each SOA. The interaction was not significant at SOAs 200 and 600 (all $F_1$ and $F_2 < 1$). However, it was marginally significant at SOA 90 in the analysis by participants, $F_1(1, 28) = 3.00, p = .0941; F_2 < 1$. For irregular verbs, participle priming (24 ms) did not differ from identity priming (36 ms), $F_1(1, 28) = 2.24, p = .1454; F_2(1, 29) = 1.33, p = .2575$, whereas for regular verbs, participle priming (22 ms) was significantly weaker than identity priming (56 ms), $F_1(1, 28) = 8.39, p = .0072; F_2(1, 27) = 4.01, p = .0552$. That is, this interaction suggested full priming for irregular participles and partial priming for regular participles.

To examine whether the amount of participle priming differed between regular and irregular verbs, a 3 x 2 ANOVA with factors SOA (90/200/600) and Regularity (‘regular’/‘irregular 2’) was conducted on participle priming. None of the effects was significant: SOA $F_1(2, 80) = 2.18, p = .1193; F_2 < 1$; Regularity ($F_1$ and $F_2 < 1$); Regularity x SOA $F_1(2, 80) = 1.38, p = .2586; F_2 < 1$. This lack of effects indicates that, overall, participle priming effects were equivalent between ‘regular’ and ‘irregular 2’ participles.

**Discussion**

Experiment 2 intended to replicate the findings of Sonnenstuhl et al. (1999) in the visual domain and thus hypothesized full priming for regular verbs and partial priming for irregular verbs. However, we found no such interaction. Our findings rather revealed that identity priming was stronger than participle priming, that is, participle priming was partial for both regular and irregular verbs. These priming patterns were stable across all SOAs (90, 200, 600). Only the data from SOA 90 showed a marginal interaction between verb regularity
and priming. However, if one wishes to interpret this interaction, it indicates full priming for irregular participles and partial priming for regular participles, and thus the opposite of the predictions of a dual-mechanism account. We discuss the indications of these results below.

**General discussion**

We investigated priming effects of regular and irregular participles in German. We were particularly interested in whether the priming effects found by Sonnenstuhl et al. (1999), which were interpreted to support the dual-mechanism account, could be replicated. The dual-mechanism Pinker/Clahsen account assumes that regular verbs directly prime each other by the activation of their joint stem, whereas the priming of irregular verbs is indirect, by means of activation of related entries in a semantic network. This should be reflected in the following priming pattern: Priming of regular participles should be equivalent to that of identical primes (“full” priming), whereas irregular participles should yield less priming than identical primes (“partial” priming).

In Experiment 1, we contrasted ‘regular’, ‘irregular 1’, and ‘irregular 2’ participles in a cross-modal paradigm. In Experiment 2, we contrasted ‘regular’ and ‘irregular 2’ participles in the visual modality, in three sub-experiments with different SOAs. We consistently observed partial priming for all verb types: ‘regular’, ‘irregular 1’, and ‘irregular 2’ verbs all showed consistently larger effects of identity primes than of participle primes (see Figure 1). This pattern solidly replicated across modalities, SOAs, and target types (first- and second-person singular targets). Therefore, taking Experiments 1 and 2 together, we have in fact evidence from four data sets (one cross-modal and three visual), compared to the one by Sonnenstuhl et al. (1999). Unequivocally, all show a pattern of results that disfavors the Pinker/Clahsen dual-mechanism account. We consistently observe partial priming even for
‘regular’ verbs, even in a cross-modal paradigm with conditions, materials and other aspects closely matched to the original Sonnenstuhl et al. (1999) study.

The hypothesis that the interaction found in Sonnenstuhl et al.’s data, which was at the basis of the arguments in favor of a dual mechanism, was indeed due to differences in identity priming between ‘irregular 1’ and ‘regular’ verbs, was also proven to be justified. We replicated this critical interaction with a subset of ‘regular’ items that were close in frequency to those used in the Sonnenstuhl et al. study (see Figure 2). Thus, this interaction seems to be driven by frequency differences between identical and participle forms of the ‘regular’ and ‘irregular 1’ items (see also Footnote 3).

Furthermore, dual-mechanism models maintain a dichotomous differentiation between a regular system and an irregular system - independent of the “amount of irregularity”. Along the gradient of verb regularity, we examined whether different subgroups of irregulars indeed behave like a homogeneous group when compared to regular verbs. However, the constant priming patterns across all verb types reveal that there is no strict dichotomy between regular and irregular verbs. We even observed that ‘regular’ verbs cluster with ‘irregular 2’ verbs and contrast to ‘irregular 1’ verbs, indicated by the main effect of Regularity (see Experiment 1). Hence, irregular verbs display differentiated patterns and are not in homogenous contrast to regular verbs.

With regard to irregular verbs, we found partial priming for ‘irregular 1’ and ‘irregular 2’ participles, as well as full priming for ‘irregular 2’ participles under visual priming at SOA 90. Even though it is not entirely legitimate to combine evidence from German with evidence from English, our results comply with the priming patterns described in the literature for English that range from full priming over partial priming to no priming at all (see Forster et al., 1987; Marslen-Wilson, 1999; Napps, 1989). However, partial priming effects for regular verbs are rather unusual in the repetition-priming literature. In English,
most studies reported full priming (Marslen-Wilson, 1999; Napps, 1989; Napps & Fowler, 1987), though there is some evidence for partial priming (Fowler et al., 1985). In Experiment 2, we demonstrated that full or partial priming for regular verbs depends on frequency rather than on regularity. With lemma frequency kept constant, ‘regular’ participles with low surface frequencies produced full priming, whereas ‘regular’ participles with high surface frequencies did not yield any priming at all. Moreover, when ‘regular’ participles with low surface frequency were compared with ‘irregular 1’ participles (overall, matched on lemma and surface frequency), the interaction of Sonnenstuhl et al. (1999) was replicated. Our findings thus demonstrate that the overriding distinction of full priming versus partial priming depends on the factor frequency.

According to the dual-mechanism approach, regular participles are accessed via their stem, and their recognition should be affected by stem frequency (as indicated by the lemma frequency), but not by their surface frequency. Our finding that surface frequency determines the priming patterns of regular participles thus provides a strong argument against the dual-mechanism account.

How can the observed frequency effects be explained? With respect to the fast recognition of high-frequency regular forms, dual-route models assume that high-frequency regular forms will establish a whole-word representation that is accessed and retrieved during recognition and that has its own frequency value (e.g., Schreuder & Baayen, 1995; Stemberger & MacWhinney, 1986). Note that faster responses for high-frequency than for low-frequency regular forms could also indicate strong connections between highly frequent stem-affix combinations rather than a separate whole-word representation (Smolka et al., 2007). Both accounts can also explain differential priming effects from high-frequency and low-frequency inflected forms. Even the absence of priming, as was observed for the high-frequency participles in Experiment 1, can be explained, for instance, in terms of access to
whole-word representations (e.g., *suited*) whose connections to other variants from the same verb (e.g., *suits*) are weak, at a form level, at a meaning level, or at both.

If full and partial priming effects are frequency-dependent, the question arises whether full and partial priming truly indicate stem access and whole word retrieval, respectively. We have recently argued (Smolka et al., 2007) that the particular identity condition used in Sonnenstuhl et al. (1999) does not represent a good measure of stem access. In German, all inflected verb forms comprise a stem and a suffix, the -e suffix for the first person singular present, the -st suffix for the second person. Hence, these inflected identity primes do not implement “stem priming” per se. Rather, both regularly and irregularly inflected forms might be decomposed into stems and affixes in similar ways – an issue that needs to be tested rather than assumed. We nevertheless applied this type of identity condition in the present study, to keep as close as possible to the design and conditions of Sonnenstuhl and colleagues.

To sum up, we found full and partial priming for both regular and irregular verbs in four separate data sets. This is sufficient evidence to argue against distinct processing styles - stem access versus whole-word retrieval - for regular and irregular participles. The finding of full priming for low-frequency regular verbs and for irregular verbs may be an indication of stem access, irrespective of regularity. Indeed, we have suggested elsewhere that both regular and irregular participles are parsed and accessed for their stem (Smolka et al., 2007).

Different processing systems? Findings on participle priming.

Above, we discussed the full and partial priming effects of regular and irregular participles and their significance for assuming different processing styles: stem access versus whole-word retrieval. Next to processing style, the number of processing systems is an important issue. Are regular and irregular verb forms processed by the same or by different
systems? To address this issue, several priming studies directly compared the amount of past-tense or participle priming between regular and irregular verbs, without measuring full or partial priming relative to an identity condition.

Here, we found the amount of participle priming to be similar across different verb regularities. Priming by ‘regular’, ‘irregular 1’, and ‘irregular 2’ participles was equivalent in Experiment 1, and priming by ‘regular’ and ‘irregular 2’ participles was similar across different SOAs in Experiment 2. These results replicate those reported in Smolka et al. (2007), in which German ‘regular’ and ‘irregular 2’ participles also primed their base verbs to the same extent.

Our findings fit well with those in other highly inflected languages. For example, in Italian, Orsolini and Marslen-Wilson (1997) compared the effects of regular and irregular past definite primes on inflected targets (either in the infinitive or in the past participle form). They found strong past-tense priming, irrespective of verb regularity and target inflection. Also regularly and irregularly inflected verb forms in French, Polish, and German were found to produce the same amount of priming (see Meunier & Marslen-Wilson, 2004, Reid & Marslen-Wilson, 2001, and Zwitserlood, 2001, respectively). For these languages, the similar patterns for regularly and irregularly inflected forms were taken as evidence against a strict distinction between two distinct processing systems—parsing of regular verbs and whole word retrieval of irregular verbs.

More recent studies in English also put the original dichotomy of regularity and irregularity into perspective. For example, Basnight-Brown, Chen, Hua, Kostić, and Feldman (2007) found equivalent priming effects between regular and irregular verbs when regular and irregular verbs were matched on aspects of semantic richness (resonance, mean connectivity, cue set size, and morphological family size).
Another study (Pastizzo & Feldman, 2002) showed that differentiations between regular and irregular verb formations in English “reflect a confound with degree of form overlap rather than compelling evidence of selective decomposition” (p. 249). Past-tense priming (measured relative to an orthographic control condition) was found for regular verbs like hatched-hatch, for irregular verbs with high letter overlap like fell-fall, but not for irregular forms with less letter overlap like taught-teach.

Overall, many studies in French, English, Italian, Polish, and German found past-tense or participle priming effects to be similar for regular and irregular verbs. Given the different priming paradigms - cross-modal priming (Experiment 1 of the present study; Basnight-Brown et al., 2007; Meunier & Marslen-Wilson, 2004; Orsolini & Marslen-Wilson, 1997; Reid & Marslen-Wilson, 2001), and visual priming at different ranges of SOA (90 ms and 200 ms in Experiment 1; 250 ms SOA in Zwitserlood, 2001; 300 ms SOA in Smolka et al., 2007; and 600 ms SOA in Experiment 2) - the experimental paradigm as such does not seem to be crucial for equivalent priming for regular and irregular verbs. Together, the data make it hard to maintain the idea of two completely independent systems for the processing of regular and irregular verbs.

It is important to remember that English was the primary driver of the original “past-tense debate”, complemented with findings in English as the test language (e.g., Forster et al., 1987; Fowler et al., 1985; Marslen-Wilson, 1999; Napps, 1989; Napps & Fowler, 1987; Kim, Marcus, Pinker, Hollander, & Coppola, 1994; Kim, Pinker, Prince, & Prasada, 1991; Pinker, 1991, 1999, 2001; Prasada & Pinker, 1993; Stanners et al., 1979; Ullman, 2001). However, language comparisons have to take into account the very different language properties. In English, the suffixation process is largely restricted to regular verbs, whereas French, Italian, Polish, Dutch and German have concatenative irregular past-tense and participle formations. German in particular possesses a very straightforward participle system: two suffixes (-t, -en)
attach to a stem (with or without vowel change). The question is rather why one should assume two different processing styles for regular and irregular participles in the first place.

Indeed, the model of Smolka and colleagues (Smolka et al., 2007; Smolka, Komlósi, & Rösler, 2008) suggests a single-system that parses complex forms like regular and irregular participles into morphemic constituents. The model can also handle English data, if irregulars are assumed to be processed as if they were stems (cf. Post et al., 2008).

The dual-system/dual-process model of Marslen-Wilson, Tyler, and colleagues (e.g., Marslen-Wilson & Tyler, 1998, 2007) can also explain the German data at hand. This account attributes processing differences to the presence or absence of inflectional morphemes (which trigger additional processing machinery over and above the basic bilateral stem access processes). Since German participles are decomposable into stems and affixes, regular and irregular participles are predicted to be processed within the same system, producing equivalent priming effects. However, English regulars and irregulars will be processed differently, because the irregular forms are not morpho-phonologically complex.

To summarize, we have shown that regularly and irregularly inflected forms in German produce similar participle-priming patterns, which renders the need to postulate two distinct processing systems superfluous. As to stem access or whole-word storage, we have shown that depending on frequency, both may be viable and can be managed within one system. Thus, our data are compatible with a single-system model that processes both regular and irregular inflection. The present conclusion must be that the distinction between regular and irregular word forms (probably not a uniform linguistic distinction itself) does not have a one-to-one mapping onto principles of psycholinguistic processing and representation.
References


**Author Note**

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Footnotes

1Irregularly inflected past tense and plural forms were mixed in this experiment.

2Clahsen (1999) and Marcus et al. (1995) argued that the relation between regular and irregular verbs in German is less skewed than that in English. However, they counted prefixed variants of a verb (e.g. *ankommen, umkommen, mitkommen*, etc.) as separate types—a practice that particularly increases the number of irregular verb types.

3In Sonnenstuhl et al. (1999), ‘regular’ identity primes (and targets) had a mean surface frequency of 3.76, a participle frequency of 19.9, and a lemma frequency of 110 per million, while ‘irregular 1’ identity primes (and targets) had a mean surface frequency of 9.62, a participle frequency of 32.6 and a mean lemma frequency of 291 per one million (CELEX database, Baayen et al., 1993). A paired $t$-test confirmed that the difference between the ‘regular’ and ‘irregular 1’ identity condition was significant, $p < .05$. 
Table 1

*German Participle Formation According to Stem and Suffix Combinations*

<table>
<thead>
<tr>
<th>Regularity</th>
<th>Citation Form</th>
<th>Participle</th>
<th>Stem</th>
<th>Suffix</th>
<th>N</th>
<th>LemF</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘regular’</td>
<td>kaufen (buy)</td>
<td>gekauft</td>
<td>infinitive</td>
<td>-t</td>
<td>1700</td>
<td></td>
</tr>
<tr>
<td>‘irregular 1’</td>
<td>laufen (run)</td>
<td>gelaufen</td>
<td>infinitive</td>
<td>-en</td>
<td>41</td>
<td>264</td>
</tr>
<tr>
<td>‘irregular 2’</td>
<td>saufen (booze)</td>
<td>gesoffen</td>
<td>vowel change</td>
<td>-en</td>
<td>144</td>
<td>194</td>
</tr>
<tr>
<td>‘irregular 3’</td>
<td>brennen (burn)</td>
<td>gebrannt</td>
<td>vowel change</td>
<td>-t</td>
<td>15</td>
<td>791</td>
</tr>
</tbody>
</table>

*Note:* Regular/irregular is used as notation. In traditional German grammars, ‘regular’ verbs are called “weak” verbs, ‘irregular 1’ and ‘irregular 2’ verbs are subsumed under “strong verbs”, and ‘irregular 3’ verbs are referred to as “mixed verbs”. All examples are given in their orthographic form, hence -en suffix, and not in their phonetic form, where the letter e is realized as schwa /ə/ or not realized at all. N = type count of monomorphemic verbs taken from CELEX (Baayen, Piepenbrock, & Van Rijn, 1993); LemF = mean lemma frequency per million.
Table 2

*Response Latencies and Accuracies in Experiment 1*

<table>
<thead>
<tr>
<th>Regularity</th>
<th>Identity Prime</th>
<th>Participle Prime</th>
<th>Unrelated Prime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>%</td>
<td>RT</td>
</tr>
<tr>
<td>‘regular’</td>
<td>505 (73)</td>
<td>1.4</td>
<td>529 (67)</td>
</tr>
<tr>
<td>‘irregular 1’</td>
<td>499 (69)</td>
<td>2.4</td>
<td>529 (67)</td>
</tr>
<tr>
<td>‘irregular 2’</td>
<td>510 (63)</td>
<td>2.2</td>
<td>545 (61)</td>
</tr>
</tbody>
</table>

*Note:* Mean RTs in milliseconds (SD) for correct responses and mean percentage of errors to ‘regular’, ‘irregular 1’ or ‘irregular 2’ verb targets preceded by themselves (identity), by their participle, or by an unrelated verb.
Table 3

*Response Latencies and Accuracies in Experiment 2*

<table>
<thead>
<tr>
<th>Regularity</th>
<th>Identity Prime</th>
<th>Participle Prime</th>
<th>Unrelated Prime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>%</td>
<td>RT</td>
</tr>
<tr>
<td>SOA 90</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>‘regular’</td>
<td>576 (115)</td>
<td>2.3</td>
<td>609 (115)</td>
</tr>
<tr>
<td>‘irregular 2’</td>
<td>602 (97)</td>
<td>4.9</td>
<td>615 (111)</td>
</tr>
<tr>
<td>SOA 200</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>‘regular’</td>
<td>532 (102)</td>
<td>2.2</td>
<td>584 (92)</td>
</tr>
<tr>
<td>‘irregular 2’</td>
<td>544 (106)</td>
<td>1.7</td>
<td>595 (99)</td>
</tr>
<tr>
<td>SOA 600</td>
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<tr>
<td>‘regular’</td>
<td>492 (86)</td>
<td>1.4</td>
<td>561 (91)</td>
</tr>
<tr>
<td>‘irregular 2’</td>
<td>508 (86)</td>
<td>2.1</td>
<td>574 (99)</td>
</tr>
</tbody>
</table>

*Note:* Mean RTs in milliseconds (SD) for correct responses and mean percentage of errors to ‘regular’ or ‘irregular 2’ verb targets preceded by themselves (identity), by their participle, or by an unrelated verb; SOA as between-subjects variable.
Figure Captions

*Figure 1.* Left side: identity and participle priming effects for ‘regular’, ‘irregular 1’, and ‘irregular 2’ verbs under cross-modal priming in Experiment 1. Right side: identity and participle priming effects for ‘regular’ and ‘irregular 2’ verbs under visual prime presentations at three levels of SOA in Experiment 2.

*Figure 2.* Identity and participle priming effects for ‘regular’ verbs with low-frequency participles (Low set of Experiment 1), and ‘irregular 1’ verbs. The data of Experiment 1 are shown together with the data on the same conditions from the study by Sonnenstuhl et al. (1999).
Figure 1