Morphological processing in younger and older people:

Evidence for flexible dual-route access

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Morphological processing in younger and older people: Evidence for flexible dual-route access

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Introduction

Chapter 1

Morphemes are among the smallest meaningful units of languages. They can be distinguished from words in that all words can stand alone while some morphemes (bound morphemes) need to be attached to a stem. Morphology is concerned with the study of how morphemes are combined and with the consequences of this process. Traditionally, linguists distinguish between inflection and derivation. The former process leads to syntactic changes in the word, such as changes in tense, mood, voice and many more. Adding the bound morpheme *-s* onto a noun can indicate plural number. In contrast, derivation is a word-formation process involving a semantic shift, often changing the lexical category. The addition of *un-* reverses the meaning of verbs; attaching *-ness* onto an adjective turns it into a noun.

The last 80 years have seen numerous debates about the mental representation of morphologically complex words. Does the mental lexicon contain all possible forms, including all inflected and derived forms? Or are these forms computed on-line and each time anew? Are there options between these two extremes?

My dissertation aims to address these issues, focusing on the comprehension of past-tense verbs and plural nouns. I will first present a brief introduction to the most influential theories of morphological processing, together with some of the early pieces of evidence in support of these theories. Then, I will layout the topics covered in the individual chapters of this thesis.

Single-Route models

Full-Decomposition models

Full decomposition, also called full-parsing models propose that during reading and listening all regular and semantically transparent morphologically complex forms are obligatorily decomposed into their constituent morphemes and that there are no stored representations of these complex forms (Taft, 1994, 2004; Taft & Forster, 1975). The assumption of a decomposed morpheme system that computes forms via a finite set of rules is not new. Bloomfield stated already in 1933 that

> most speech-forms are regular, in the sense that the speaker who knows the constituents and the grammatical pattern, can utter them without ever having heard them; moreover the observer cannot hope to list them, since the possibilities of combinations are practically infinite. (p. 275)

Chomsky and Halle (1968) hypothesize that the lexicon contains only idiosyncratic entries that are not predictable (generated by a rule), whereas all regular variations such as the pluralization of nouns by adding an *-s* are the results of rule-based computations. Evidence favoring this view comes from several subdisciplines within the field of psycholinguistics.

One of the best-known findings in First Language Acquisition is overregularization (Berko, 1958; Ervin, 1964; Kuczaj, 1977; Marcus et al., 1992). This phenomenon describes the normally developing child as going through three phases when acquiring irregular past tense forms. In the beginning, children produce the correct forms as they simply repeat the input they receive, thus using *went* as the past tense of *go* as the people around them do. After that, many children go through a phase of producing incorrect words such as **goed* and **breaked* as they discover the rules applying to their native language, such as [stem]+*ed* in English. Finally, children recognize the irregular past tense forms as exceptions from regular past-tense morphology and memorize the correct forms while sticking to rules for regular past-tense morphology. This course of development has often been cited as evidence for a rule-based system of morphology since it is very unlikely that children picked up the incorrectly regularized forms in the input and stored them via rote learning (see e.g. Brown & Bellugi, 1964; Lenneberg, 1964; McNeill, 1966; Slobin, 1971; Pinker & Prince, 1988, 1991; Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995).

Another classic piece of evidence, again from the domain of developmental psycholinguistics is "the wug study". Berko (1958) famously elicited the plural and possessive inflections of nonword nouns (e.g. "wug") as well as progressive, past-tense, and third-person-singular inflections of nonword verbs. She found that most first-graders know how to produce regular verb and noun inflections. Similar to the previously mentioned overregularization, these findings suggest that children possess a set of rules that they use to inflect new words.

Murrell and Morton (1974) used tachistocopic exposure to assess people's recognition of words. When pre-trained with an inflected form of the target word, recognition was facilitated. This was however not the case if the pre-trained word was only visually or acoustically similar but not morphologically related to the target. *Cars* facilitated the recognition of *car*, but *card* did not. It is plausible that complex words are decomposed into their morphemes with an assigned specific semantic association. Exposure to an affixed form of the morpheme then primes its constituent morphemes and thus leads to facilitation in the recognition of these morphemes. The lack of difference between training and no training with visual-acoustically similar words shows that priming effects between morphologically similar words are not due to a mere form overlap.

Taft and Forster (1975) claimed that people always "strip off" affixes and that bound-morpheme stems (e.g. the non-existing forms **juvenate*, **vive*) are stored in the mental lexicon, even if they never occur on their own. In their study, lexical decision times for these nonwords were longer than for pseudo-stems (i.e. nonwords formed by the removal of a first syllable that was homophonous to a real prefix but did not act as a morpheme, e.g. **pertoire* or **gulate*), which are arguably not stored as separate entries in the lexicon (Taft & Forster, 1975). Subsequent studies appeared to limit affix stripping to prefixes and inflectional suffixes (for reviews, see Taft, 1988, 1991).

There is little work on morphological processing during word production. In an implicit priming experiment (Roelofs, 1996), participants learned associations between prompts and target words. Response latencies were shorter when the target words occurred in a so-called homogenous sets (i.e., target words shared the first morpheme: *intake, inward, inverse*) compared to when they occurred in heterogeneous sets (i.e., first morphemes of target words were different: *intake, outrun, uplift*). Importantly, this "preparation effect" was larger when the overlapping syllable constituted a morpheme (e.g., *intake*) compared to a mere form overlap (e.g., *Indian*). A follow-up study (Roelofs & Baayen, 2002) revealed that semantic transparency did not influence the size of this preparation effect (*intake* yields similar effect as *invoice*). Similar results were found for the production of verbs (Lüttmann, Zwitserlood, & Bölte, 2011) and compounds (Lüttmann, Zwitserlood, Böhl, & Bölte, 2011) in German. In both studies, visual distractor words (e.g. *shoebox*, *chatterbox*) facilitate the naming of a morphologically related picture (e.g. *mailbox*), regardless of semantic transparency.

Full-decomposition models have been criticized for the implausibility of obligatory affix-stripping. Relying on strict left-to-right parsing may easily lead to misparsings in pseudo-prefixed words (e.g. *begin*). Schreuder and Baayen (1994) reported that 30% of Dutch words begin with a word that could be a prefix (but does not act as one); for English, the number goes up to 80%. Pseudo-suffixation is less of a problem. Kemps, Ernestus, Schreuder, and Baayen (2005) calculated that that in Dutch stem-sharing occurs ten times more often for morphologically related words (e.g. *book* and *books*) compared to unrelated words (e.g. *ham* and *hamster*). The authors found evidence that listeners are able to use prosodic cues in the stem to determine the morphological context of a word, suggesting that plural forms are not necessarily processed as a string of morphemes as they appear in writing.

Full-Listing Hypothesis

Butterworth (1983) presented the most cited work favoring a full-listing account of morphologically complex words. As the name implies, this model assumes the existence of a list of fully inflected words, possibly grouped by their base forms. Advocates of a decompositional view have often explained the need for a rule-based system by the large memory load that a full listing of all possible forms would require (Forster, 1976). By contrast, Butterworth argued that, in turn, the computations necessary for decomposition would lead to an increased processing load. Furthermore, lexical entries need some sort of specification as to which rules can be applied to them, which would similarly "increas[e] the memory load to proportions comparable with the

[Full Listing Hypothesis] model." (Butterworth, 1983, p. 262) The author supports these theoretical assumptions by referring to findings in the literature.

For instance, Rubin, Becker, and Freeman (1979) measured subjects' lexical decisions for prefixed (e.g. *absent*, *disappear*) and pseudo-prefixed words (e.g. *abbey*, *disaster*), either in a prefixed context (i.e. the filler words were prefixed words or nonwords) or in a non-prefixed context. They found longer reaction times in the prefix-context for both types of words. It seems that people can be encouraged to decompose both prefixed and pseudo-prefixed words, but computational processes associated with decomposition slow the listener down. Thus, it was argued, decomposition seems an unlikely strategy to employ on the basis of normal daily interaction, which does not exist solely of prefixed words.

Another piece of evidence stems from Patterson's (1982) reports of a patient who, classified as "phonological dyslexic", was unable to read nonwords. His ability to read real words was fairly intact, however, he made morphological mistakes. When asked to produce *think*, he responded with *thinking*, when the target was *offend*, the patient answered with *offense*. Interestingly, the patient was well able to distinguish invalid combinations of real word stems and real affixes (e.g. **fearest*, **passly*) from similar existing words (*nearest*, *costly*), suggesting that he made use of a full listing of forms in his mental lexicon.

However, evidence for a full listing account is scarce. It is important to note that Butterworth (1983) explained all contradicting evidence by pointing out that his claim for full-listing does not imply the complete absence of rules. In fact, he believed that there may be "fall-back procedures" (p. 290) coming into action for instance when one encounters a new word. He does not dispute the possibility of a rule system explaining the u-shaped development of irregular verb morphology. However, Butterworth counters by asking how we would know if a child might not construct regular forms such as *spank-ed* only once, store them in their lexicon, and subsequently draw on this one form instead of computing it each time anew. The default is assumed to be a list with separate entries for complete forms, organized by the base form and mapped onto common semantic units.

Connectionist models

The advent of computers in the second half of the 20th century led to a new subdomain in the cognitive sciences that modeled cognitive processes. These parallel distributed processing models or connectionist models are implemented as networks consisting of (distributedly represented) units (nodes), which correspond to features, phonemes (or letters) and words; these units are connected between levels of representation (e.g., phoneme level to word-form level) and compete within each level (e.g., phoneme to phoneme). Rumelhart and McClelland (1986, 1987) presented one of the first models to simulate the acquisition of past tense in English; later models addressed the acquisition of noun plurals as well (e.g., Plunkett & Juola, 1999). The process of morphological acquisition means learning input-output associations. That is, during the comprehension process, the model gets an input of word tokens and compares what was "heard" with the token that the system would have expected to "hear" (given the current semantic and syntactic context), the output. If there is a mismatch, modification occurs. This learning process means adjusting the strengths of connections and threshold values, so that the discrepancy between some input and its actual output is minimized. Similarly, during the production process, a hypothesis generator describes the best guess of an inflected form at that point in development.

Proponents of connectionist models claim that they are able to simulate key findings of morphological processing research, such as the aforementioned u-shaped development of the acquisition of (ir-)regularity (Daugherty & Seidenberg, 1992; Rumelhart & McClelland, 1986; Plunkett & Marchman, 1991; MacWhinney & Leinbach, 1991), dissociations between regular and irregular verbs in aphasic patients (Westermann & Ruh, 2012).

Closely related to connectionist models, analogical models assume that speakers can build upon existing linguistic knowledge through analogies, thereby producing output that is hard to capture under a rule-based account such as allomorphy in regular Dutch past-tense formation. Ernestus and Baayen (2003) asked native speakers to form the past tense of pseudoverbs. It appeared that the participants used analogies with phonological neighbors to determine which allomorph is appropriate. In a similar manner, when English native speakers are asked to form the past tense of the nonword *spling*, they find *splung* very acceptable (in analogy to *spring*, *sting*, *swing*, *fling*, etc.; Albright & Hayes, 2003; Prasada & Pinker, 1993; Bybee & Moder, 1983). Albright and Hayes (2003) suggest

Importantly, as single-system models, connectionist models refute an inherent distinction between regular and irregular words. This captures the fact that what is irregular about verbs is usually only their simple-past and/or their participle form but not other inflections, such as 3rd person singular. Instead, it is argued that a single network is able to replicate patterns of human behavior (see Christiansen and Chater, 1999, for an overview).

Dual-Route models

In an influential paper, Pinker and Prince (1988) criticized the Rumelhart-McClelland model on several grounds, for example that it cannot handle homophones with different past tense forms (*ring-rang* vs. *wring-wrung*). Other scientists see the weakness in connectionist models in the fact that they are only concerned with input and output instead of the steps in-between.

Pinker and Prince (1994) proposed a dual-route model, assuming two different systems, one responsible for regular, the other for irregular verb morphology. The regular rule system leads to predictable results and is readily applied to nonce stems. The memory system on the other hand is concerned with irregular words, which are associatively stored in the memory. These irregular forms cannot be predicted from the stem. They occur in high-frequency items (that is, words that occur often in the language) or within families of similar stems (e.g., *ride-rode, drive-drove, write-wrote*) or both. In later publications, Pinker refers to the two subsystems as Lexicon and Grammar (Pinker & Ullman, 2002) with the former being a part of the declarative memory and the latter depending on the procedural memory system (Ullman et al., 1997). There is a number of studies indicating that this dual process for verb inflection might indeed exist.

Stanners, Neiser, Hernon, and Hall (1979) showed that, while repetition priming is as effective as inflectional priming for regular verbs, there were differences between these two forms of priming for irregular verbs. The latter showed a much stronger priming effect for repetition priming than for inflected priming. That is, while *pours*, *pouring* and *poured* prime *pour* to a similar degree as *pour* itself, *shake* was much more facilitated by the prime *shake* than by *shook*. This indicates differential access and storage of regular vs. irregular verbs (see Sonnenstuhl, Eisenbeiss, and Clahsen, 1999, for similar findings in German, as well as Smolka, Zwitserlood, and Rösler (2007) who found no difference between regular and irregular past-participle inflections).

Furthermore, the more frequent a given irregular form is, the faster it is recognized. This means that a very frequent irregular form like *made* will be recognized much faster than a very rare irregular form like *swung*. However, there are no differences in reaction times between frequent regular forms, like *walked*, and infrequent irregular forms, like *glazed* (Bybee & Slobin, 1982; Prasada, Pinker, & Snyder, 1990, but see Woollams, Joanisse, & Patterson, 2009). This so-called form frequency effect is often taken as evidence for storage of particular forms. As memory traces get stronger with additional exposure, more frequent irregular forms yield shorter reaction times because these forms are stored. As regular forms are decomposed into their constituent morphemes, the frequency of the form does not influence reaction times.

Convincing evidence towards the dual nature of the language faculty stems from clinical work in the form of double dissociations. If two processes can be separately impaired, so the argument goes, they must be governed by two separate systems of processes or representations. This is the case for Specific Language Impairment (SLI) and Williams Syndrome (WS), which seem to affect different linguistic phenomena. Patients with SLI perform rather poorly on linguistic tasks in light of their normal cognitive abilities, whereas patients with WS show severe mental retardation but are known for a verbose and very expressive, if lexically deviant, speech style.

Clahsen and Almazan (1998) compared children with WS to normally developing children matched for mental age and children with SLI from previous studies (van der Lely, 1996; van der Lely & Stollwerck, 1997; van der Lely & Ullman, 1997; Oetting & Horohov, 1997). There was a clear dissociation in skills between the two differentially impaired groups of subjects. The children with WS performed en par with or even better than normally developing children with respect to the comprehension of passives as well as the production of regular past-tense inflection of existing and nonce verbs. Their performance on irregularly inflected past-tense verbs, however, lagged behind that of normally developing children and even that of children with SLI. In contrast, the children with SLI had lower than normal scores on all other morphological processes tested. Furthermore, they produced a great number of bare base root forms without any inflection. This led to the conclusion that WS patients have an intact computational system, which allows for regularized mechanisms such as constructing regular past-tense forms. Yet their associative memory system is impaired. Children with SLI, on the other hand, often show a dysfunction of the computational mechanism underlying regular past-tense formation with other cognitive functions spared (Bishop, 1994). As a coping mechanism, SLI children store regularly inflected past tense forms in the same way healthy people store irregular forms, instead of computing them on the spot (van der Lely & Ullman, 1997).

Similarly, Marslen-Wilson and Tyler (1997) were able to show selective priming in two agrammatic aphasics with damage in the left hemisphere. The authors elicited facilitation for the uninflected stem of a word by priming with its irregular past tense form (*found* primes *find*) but found no such effects for these patients when using regular past tense forms to prime their stems (*jumped* did not prime *jump*).

Münte, Say, Clahsen, Schiltz, and Kutas (1999) compared event-related brain potentials to English regular and irregular stems that were preceded by either their own past-tense form (priming) or a different past-tense form (no priming). The authors found that for the regular forms, priming led to a reduced N400 component (usually associated with ease of lexical access), but there was no such effect for inflected forms of irregular items or items with a mere form overlap. Similar results were found for German (Weyerts, Münte, Smid, & Heinze, 1996) and Spanish verbs (Rodriguez-Fornells, Münte, & Clahsen, 2002).

Importantly, while the dual-route model proposes differential routes of access for irregular and regular words, it does not refute the possibility of storage of regular forms. Pinker and Prince (1994) pointed out that this is the case for children acquiring their first language and for SLI patients who perform far better with irregular verbs due to their high relative frequency. In fact, there is evidence that highly frequent regular verb forms are indeed stored despite their morphological complexity (Alegre & Gordon, 1999; Stemberger & MacWhinney, 1986; Lehtonen & Laine, 2003; Lehtonen, Niska, Wande, Niemi, & Laine, 2006; Soveri, Lehtonen, & Laine, 2007).

Schreuder and Baayen (1995) proposed a parallel dual-route race model, where the computational route as well as the storage route are activated at the same time. Upon encountering a morphologically complex word, the former decomposes the forms while the latter looks up the whole word in the mental lexicon. The route that leads to a decision the fastest "wins out". This model explains findings concerning the processing of noun plurals which seem to be accessed via parsing as well as from storage (Baayen, Dijkstra, & Schreuder, 1997; Baayen, McQueen, Dijkstra, & Schreuder, 2003; New, Brysbaert, Segui, Ferrand, & Rastle, 2004; Dominguez, Cuetos, & Segui, 1999; Baayen, Burani, & Schreuder, 1997).

However, this flexibility of dual-route models can also be seen as a point of criticism. The models are able to account for a vast majority of findings; it seems overly convenient that in a given situation, the route that is able to capture the findings is the one that is activated, or faster, depending on the specific model. This virtual omnipotence has led psycholinguists to study the factors that influence which of the two routes is the one that is used in a specific situation. A number of linguistic factors have been established in the past. Some of these factors are, as mentioned above, frequency and regularity, as well as affix type (Cole, Beauvillain, & Segui, 1989; Cutler, Hawkins, & Gilligan, 1985; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Taft, 1994), semantic transparency (Marslen-Wilson et al., 1994; Feldman & Soltano, 1999, but see Roelofs & Baayen, 2002; Lüttmann et al., 2011; Andrews & Lo, 2013), affixal productivity and homonymy (Bertram, Laine, & Karvinen, 1999; Bertram, Schreuder, & Baayen, 2000).

In this thesis, I will add to these linguistic factors that influence the processing of inflected words. Further, I will investigate cognitive factors such as working memory and task demands, whose influences have not been studied with regards to morphological processing, to the best of my knowledge.

One of these factors is age. Most studies on morphological processing concentrate on a younger population, often Psychology undergraduates. The influence of age is rarely investigated. How might age affect morphologically processing?

One possibility is that the morphological processing in older people is altered due to age-related decline in computational processing. The decompositional route has been argued to be more demanding on the processing system (Laine, Vainio, & Hyönä, 1999). This might lead to a smaller degree of decomposition and a greater reliance on whole-word access in older people.

At the same time, higher age means a greater exposure to and experience with inflected forms. Greater exposure to a certain form makes it easier to recognize and might lead to whole-word access of regular forms, analogous to effects of form frequency for high-frequency regular forms (Alegre & Gordon, 1999; Lehtonen & Laine, 2003).

On the other hand, research has shown that morphological decomposition happens early during comprehension and that it is a highly automatic process (Rastle & Davis, 2008). It is also possible that the automaticity of the parsing process keeps necessary capacities at a minimum, so that age does not influence morphological processing at all.

Content of this thesis

All chapters compare the performance of a young student sample to a group of older participants.

In Chapter 2, I address working-memory load as a factor influencing morphological processing in two comprehension experiments with Dutch past-tense verbs. Chapter 3 investigates the differential imwpact that pseudoword material and related task demands have for the two different age groups in a lexical decision task. In Chapter 4, I turn to Dutch plural nouns and the influence of word class and frequency on morphological processing. Chapter 5 examines how morphological richness influences the way plural nouns are processed. For this reason, I conducted experiments in German due to its greater morphological richness. Lastly, in Chapter 6, I will summarize the findings and discuss their implications.

The influence of memory load and age on the processing of Dutch past-tense forms

Chapter 2

Abstract

Models of the mental representation of morphologically complex words traditionally fall into one of two categories, single-route or dual-route models. The former further distinguish between full-listing and decomposition, while the latter assume different systems governing the access of regular vs. irregular words. One of the main arguments against decomposition and continuous online computations is the cognitive resources this process would require. Taxing someone's working memory capacities should then uniquely affect the computation of morphologically complex regular verb forms. We expect an increase of cognitive load to lead to a higher increase reaction times in processing regular inflected forms compared to irregular inflected forms.

Further, we compared younger and older participants; with increased age, people accumulate a large number of encounters with inflected forms. This greater experience may lead to storage of both regular and irregular forms, which would be indicated by a form frequency effect for all inflected forms.

We tested these hypotheses with an auditory (Experiment 1, $N = 48$) and a visual (Experiment 2, $N = 48$) lexical decision task, comparing reactions to Dutch regular and irregular past tense forms, both under low and under high cognitive load. We found that frequency influenced reaction times to irregular but not to regular forms, favoring a listing account for the former but a computational procedure for the latter forms. This interaction, however, was present only for young people. Older participants showed no regularity-by-frequency interaction, indicating that they process regular and irregular forms in a similar manner. There was no effect of the load manipulation.

It seems that age influences the storage of and access to morphologically complex verb forms. While younger people compute morphologically complex inflections on-line, older people seem to rely more on a list-like storage for regular forms as well.

The last 80 years have seen numerous debates on the processing and memory representation of polymorphemic words. Does the mental lexicon contain a representation for each individual word form, whether morphologically simple or complex? Or are complex words decomposed and computed online from their parts each time anew? Is there more than one option?

Models addressing the processing of morphologically complex words can usually be categorized into single- or dual-route models. The former assume that all forms are processed in a similar manner. Butterworth (1983), for example, claimed that all known words are stored in the mental lexicon, whether morphologically simple or complex. He argued that on-line computations of morphologically complex forms would lead to increased processing load, making this an unlikely strategy. However, empirical evidence for this full-listing account is scarce, and the few rather dated studies that do exist mainly rest on case reports (e.g. Patterson, 1982) and focus on refuting the findings of pro-decomposition studies instead of substantiating their own account (see e.g. Rubin, Becker, & Freeman, 1979). On the other end of the single-mechanism continuum stand pure parsing models. According to these theories, all morphologically complex forms are obligatorily decomposed into their constituent morphemes and only simplex bare stems and affixes are stored (e.g. Taft, 1979, 2004).

Another type of single-mechanism theory are connectionist accounts that model cognitive processing in terms of networks of units corresponding to concepts or features. According to these models, learning involves adjusting the strengths of connections and the threshold values, so that the discrepancy between an input and its output is minimized. Rumelhart and McClelland (1986, 1987) presented a parallel distributed processing model to simulate the acquisition of English past tense. The performance of these models used to depend heavily on the nature of the input and on output representations (cf. Seidenberg & McClelland, 1989). Currently, more generalized models, such as the triangle model by Seidenberg and colleagues (Harm & Seidenberg, 1999, 2004; Seidenberg & Gonnerman, 2000) and the amorphous morphology model (Baayen, Milin, Filipovic Đurđević, Hendrix, & Marelli, 2011) take phonological knowledge as well as orthographic representations into account.

Dual-route models, on the other hand, allow for fundamentally different processes to be at work: traditionally, one process is responsible for regular morphology, the other for irregular morphology. Regular inflected forms are computed by applying a set of rules to their stem, leading to predictable results. In contrast, all surface forms of irregular verbs are stored in lexical memory. Models differ in whether they assume two different mechanisms in one system (Schreuder & Baayen, 1995; Frost, Forster, & Deutsch, 1997) or two largely independent systems (e.g. lexicon vs. grammar in Pinker & Ullman, 2002; procedural vs. declarative system in Ullman et al., 1997).

The first question of the current research was whether comprehension of Dutch verbs is governed by a single- or a dual-route mechanism. Morphological research has been dominated by work on English verb (and occasionally noun) morphology. Some other languages have been investigated[1], but Dutch has received relatively little attention. There are some studies on Dutch nouns (Baayen, Dijkstra, & Schreuder, 1997; Baayen, McQueen, Dijkstra, & Schreuder, 2003), but research on Dutch past-tense

[1] French, Meunier & Marslen-Wilson, 2004, German, Smolka, Zwitserlood, & Rösler, 2007, Sonnenstuhl, Eisenbeiss, & Clahsen, 1999; Penke et al., 1997, Hebrew: Frost, Forster, & Deutsch, 1997; Italian, Orsolini & Marslen-Wilson, 1997; Gross, Say, Kleingers, Clahsen, & Münte, 1998; Caramazza, Laudanna, & Romani, 1988.

verbs remains scarce, and a comparison between regular and irregular verb inflections is lacking (see Bertram, Schreuder, and Baayen (2000) on regular verb morphology).

To address the storage vs. computation issue, we made use of a well-known diagnostic tool: word frequency. Importantly, a distinction should be made between form (or surface) and lemma (or stem) frequency. If each inflected form of a verb is stored and accessed individually, one would expect frequency effects for these individual forms. If inflected forms are computed and only their stems are stored, one would expect stem-frequency effects – as reflected by lemma frequency[2]. By investigating the influence of form frequency for regular and irregular verb forms, we hope to arrive at a clearer picture of the nature of Dutch verb processing. If reactions to both regular and irregular verbs show a similar pattern, this supports a single-mechanism process. If, on the other hand, regular and irregular verbs behave differently (more specifically, if there is a form-frequency effect for irregular verbs but not for regular verbs), this supports a dual-mechanism view.

In addition to addressing differences between regular and irregular verb forms, we include two novel aspects. The first concerns processing costs: assuming that computational processes are necessary for the comprehension of morphologically complex words, are they cognitively costly? Phrased in terms of working memory, do decomposition, maintenance of constituent morphemes, and subsequent re-assembly

[2] In CELEX (Baayen, Piepenbrock, & Gulikers, 1995), lemma frequencies are the sum of the form frequencies of all inflections of a word of the same word class. That is, the lemma frequency for *bergen* ('to store') is the added frequency of *berg* (1st person singular present tense), *bergt* (2nd and 3rd person singular present tense), *bergen* (plural present tense), *borg* (singular past tense), *borgen* (plural past tense), etc. Note that its lemma frequency does not include the form frequency for the noun *berg* ('mountain').

take time and tax cognitive resources? A second question concerns the rigidity or flexibility of lexical representations and processes: how stable or flexible is the structural organization of the mental lexicon? Here, we compare younger and older participants, with different amounts of life-time experience with verb forms. In what follows, we first summarize the evidence in favor of dual-mechanism models from verb processing. This is followed by a brief introduction to the role of working memory, and the flexibility of lexical organization as a function of experience. Finally, we specify the conditions and predictions of our study.

Dual-Route Mechanisms

There is a considerable body of evidence suggesting that verbal inflection follows two different routes, depending on whether a word is regularly or irregularly inflected. More than 30 years ago, Stanners, Neiser, Hernon, and Hall (1979) observed differences in the primeability of regular and irregular verbs. For regular verbs, inflectional priming (*lived – live*) was as effective as identical priming (*live - live*), whereas identical priming was more effective for irregular verbs. This was taken as evidence that regularly inflected verbs access their stem, while irregular verbs are stored as individual forms. This pattern was replicated in quite a few studies (in English: Napps, 1989; Marslen-Wilson, Hare, & Older, 1993; Marslen-Wilson, 1999; in German: Sonnenstuhl, Eisenbeiss, & Clahsen, 1999). However, evidence against a distinction between regular and irregular morphology was also reported, showing similar priming effects for irregular and regular forms (Meunier & Marslen-Wilson, 2004; Orsolini & Marslen-Wilson, 1997; Forster, Davis, Schoknecht, & Carter, 1987; Smolka, Zwitserlood, & Rösler, 2007).

So, the picture from priming is far from clear, and frequency measures have become a popular additional tool. As explained above, dual-mechanism models predict full-form-frequency effects for irregular, but not for regular verbs, which was indeed found in a number of studies (Bybee & Slobin, 1982; Prasada, Pinker, & Snyder, 1990, Ullman, 1993; but see Daugherty & Seidenberg, 1992, 1994; Woollams, Joanisse, & Patterson, 2009). This pattern supports the view of a different routine for regular vs. irregular verbs. Irregular forms stored in the lexicon will display effects of word-form frequency, as memory traces for individual verb forms become stronger with additional exposure. This is not the case for regular forms that are computed anew; here, only stem-frequency effects are expected. Bertram et al. (2000) indeed report influences of stem frequency but not of form frequency for inflected regular verbs, indicating that these are computed and not stored.

More support comes from clinical work, from double dissociations, in which one system is severely impaired whereas the other is spared. Williams-Syndrome patients (Clahsen & Almazan, 1998) as well as people with semantic aphasia (Marslen-Wilson & Tyler, 1997) or temporal lobe damage (Tyler, Randall, & Marslen-Wilson, 2002) often have an intact computational system that allows them to process regular morphology with few mistakes. Yet they fail to retrieve information from lexical entries, as their long-term memory is impaired, leading to difficulties with irregular verbs. On the other side, patients with Specific Language Impairment (SLI; van der Lely, 1996; van der Lely & Stollwerck, 1997; van der Lely & Ullman, 1997; Oetting & Horohov, 1997) as well as patients with agrammatic aphasia (Marslen-Wilson & Tyler, 1997) display dysfunctions of the computational mechanism underlying regular past-tense formation, while other cognitive functions, including a memory system for irregular verb forms, are spared. Van der Lely and Ullman (1997) postulated that persons with SLI store regularly inflected past tense forms, instead of computing them on the fly. Similarly, patients with Parkinson's disease make more errors in regular morphology than in irregular morphology, a pattern opposite from that of people with Alzheimer's disease, whose production of irregulars is more severely impaired (Ullman et al., 1997). These types of double dissociation are usually taken as evidence for separate mechanisms that can be independently impaired by neuropathology (Shallice, 1988).

Finally, researchers have postulated distinct neural substrates for the two systems based on results of studies using brain imaging techniques such as PET and fMRI (Ullman, Bergida, & O'Craven, 1997; Rhee et al., 2001; Ullman, 2001, 2004; Jaeger et al., 1996). ERP studies examining verbal inflections also revealed distinct ERP patterns for violations of regular vs. irregular morphology (Penke et al., 1997; Gross, Say, Kleingers, Münte, & Clahsen, 1998; Newman, Izvorski, Davis, Neville, & Ullman, 1999) and for priming effects in regular vs. irregular verbs (Münte, Say, Clahsen, Schiltz, & Kutas, 1999). In sum, support for two different mechanisms of verb processing seems pervasive, but note that there are studies that do not find differences between regular and irregular morphology (see Smolka et al., 2007).

The Role of Working Memory

Decomposition and composition of complex words, including inflected verbs, may tax working memory. Because of this assumed increase in processing load, Butterworth (1983) rejected a decompositional view in favor of storage of all forms. The memory component most likely involved in such computations is the phonological (or articulatory) loop, a component of working memory proposed by Baddeley and colleagues (Baddeley & Hitch, 1974; Baddeley, 1999, 2000). Together with the visuospatial sketchpad and the episodic buffer, the phonological loop subserves the central executive in temporarily storing and manipulating information necessary for complex tasks, such as language processing. Holding verbal and acoustic information, the loop serves as a storage and rehearsal system. Would limiting available cognitive resources by straining the working memory system in turn impede morphological processing?

While decomposition is generally assumed to be more demanding and prone to errors than access from storage (Laine, Vainio & Hyönä, 1999), evidence for the involvement of working memory in the processing of complex verbs is rare. An exception is unpublished work by Ullman, Walenski, Prado, Ozawa, and Steinhauer (under revision). The authors used a version of the 2-back production task, in which participants silently read a sequence of regularly and irregularly inflected verbs repeated the form they had seen two trials before, thereby taxing the executive system. The classic n-back procedure (in which participants monitor a series of stimuli and react whenever the current stimulus is identical to one they had seen n items earlier) is often used as a test of working memory; in this case, it was expected to offer insight into the differential performance for regular vs. irregular verbs. The participants indeed made more errors recalling regularly inflected verbs compared to irregular verbs, indicating that the regular inflections are computed on-line and thus more dependent on sufficient procedural capacities. While this finding held for both highly frequent (e.g. *looked* vs. *took*) and rather infrequent verbs (e.g. *glazed* vs. *wrung*), the effect was much stronger for the latter group, suggesting that at times, high-frequent regulars are also stored in memory and accessed as single forms. This suggests that working memory is indeed involved in the computation of regularly inflected forms.

Stability / Flexibility

The mental lexicon is not a static list of entries. Instead, research has indicated that its structural organization is malleable and subject to a number of factors. One of these factors is experience. The more often a word is encountered, the easier it becomes to recognize. This phenomenon is captured in the frequency effect – calculated on the basis of (text) corpora, as an approximation of the experience with a word for the language community. It is conceivable that with added exposure to a certain inflected form, the memory traces for this very form become stronger. There is evidence that regular verbs of high frequency (for English: above 6 per million, Alegre & Gordon, 1999; for Finnish above 100 per million, Lehtonen & Laine, 2003; see also Stemberger & MacWhinney, 1986; Lehtonen, Niska, Wande, Niemi, & Laine, 2006; Soveri, Lehtonen, & Laine, 2007) are accessed via their stored full-form, rather than being computed.

Frequency of occurrence in the language environment is an approximation of experience of the language community, but not of individual experience. Clearly, a five-year-old has had less opportunity to encounter the verb *awaken* than a 60-year-old. Language users accumulate encounters with inflected forms over the course of their life, and older people have had more experience with particular word forms than younger people. So, age may influence the way people process inflected forms, such that older age leads to a higher tendency to store and access decomposable forms as single chunks. Note that this hypothesis is not incompatible with the assumptions of dual-mechanism models, as these vary with respect to their claims about regulars. While some researchers propose that all regulars are decomposed and re-assembled (Tyler et al., 2002; Marslen-Wilson & Tyler, 1998), others allow for the possibility of both assembly and storage of regular forms (parallel dual route models by Schreuder & Baayen, 1995; Augmented Addressed Morphology model by Caramazza, Laudanna, & Romani, 1988).

Our study aimed to address the cognitive costs and the factor of age during the comprehension of polymorphemic words. As previously pointed out, Ullman et al. (under revision) used an n-back procedure to investigate the influence of working memory on the production (or rather, repetition) of past-tense forms. Although our experiment is of a similar background, the approach differs significantly.

While classified as a production experiment, the actual task used by Ullman et al. (under revision) was to repeat previously read inflected forms. Although cognitive abilities are of importance in this process, other factors, such as individual differences in primeability (e.g. Plaut & Booth, 2000), may come into play as well. We will circumvent this by employing a classic lexical decision task as a measure of speed of comprehension. Future work may address production in a more direct fashion, such as picture naming.

Further, as there was no 0-back task, the authors did not report a low/no-load condition that could serve as a direct baseline comparison. We will instead use working memory load as a 2-level within-subjects factor so as to directly compare its influence on people's performance.

Lastly, despite having measured reaction times, the authors reported no differences in that regard but relied instead on accuracy. Instead, we will measure response latencies on correct lexical decisions.

Design

We used a 5-factor design with cognitive load (low - high), regularity (regular - irregular), form frequency (continuous), and lemma frequency (continuous) as within-subjects factors and age (young - old) as between-subjects factor. As for main effects, high cognitive load is expected to have a negative influence on reaction times. Frequency is expected to have a positive influence on the speed of the lexical decision.

Further, we expect an interaction between load and regularity. While responses to both regular and irregular words are likely to be slower under high load, we expect this effect to be stronger for lexical decisions on regular past tense verbs as increased load should especially impair the computational processes (decomposition, maintenance and re-assembly) necessary for morphologically complex verbs.

Lastly, we expect age to affect reactions in two ways. First, older people are expected to respond more slowly due to decreased general processing speed. Second, the greater life-long exposure to inflected forms may lead to a different pattern in the interaction of frequency and regularity as a function of age.

Experiment 1

Method

Participants

The experiment was conducted with 48 native speakers of Dutch (7 left-handed, $M_{Age} = 41$, $range_{Age} = 18\text{-}84$). The younger age group (17 female, $M_{Age} = 21$, $range_{Age} = 18\text{-}35$) and the older age group (10 female, $M_{Age} = 66$, $range_{Age} = 44\text{-}84$) consisted of 24 participants each.

Of the younger sample, 21 participants were university students or graduates, two participants had finished a technical or vocational training, and one participant indicated secondary education as his or her highest educational level. Of the older sample, seven were university graduates, 14 had finished technical or vocational training, and three indicated secondary education as their highest educational level.

All participants stemmed from the participant pool of the Max Planck Institute for Psycholinguistics, reported having normal or corrected-to-normal vision, and were paid for their participation. All participants provided informed consent to participate in the study and all data were analyzed anonymously.

Materials

The stimuli consisted of 80 Dutch words and 80 nonwords. Half of the existing words were regular, the other half irregular. These were matched for lemma and form frequency as reported in CELEX (Baayen, Piepenbrock, & Gulikers, 1995), $t(152) = .004$, $p = .997$ (lemma frequency) and $t(152) = .205$, $p = .838$ (form frequency). While the items of interest were the past-tense singular forms of the verbs (target items)[3], we included present-tense singular inflections (filler items) to minimize potential priming.

The items were randomly assigned to one of two lists, so that no present-tense form of a given verb appeared in the same list as its past-tense counterpart. This was done to avoid form priming (Stanners et al., 1979). Each of the resulting two lists contained 40 target items.

[3] The *Onvoltooid Verleden Tijd* (lit 'Unfinished Past Tense') of weak/regular verbs in Dutch is formed by suffixing *de(n)* or *te(n)* onto the stem, leading to *werkte* ('worked') and *speelde* ('played'), respectively. Strong/irregular verbs show a variety of changes, e.g. ablauting (*bieden* *bood*, 'to offer') and consonantal alternation (*kopen* – *kocht*, 'to buy').

Of the 80 nonwords, 21 were overregularized forms of irregular verbs, e.g. **graafde* (correct form: *groef*) or **zinkte* (correct form: *zonk*). An additional 11 nonwords were 'pseudo-irregulars'. They were constructed by exchanging the vowel phoneme of an existing irregular simple-past form with another vowel phoneme, e.g. **malk* (correct form: *molk*) or **praas* (correct form: *prees*). The rest of the nonwords were phonologically legal letter strings. See Table A2 in the Appendix for the included nonword items.

Furthermore, we created a list of 160 load digit strings and 160 probe digit strings. Half of these strings consisted of two digits (low load), the other half consisted of five digits (high load). The complete lists of 160 items each were divided into four blocks, two low-load blocks and two high-load blocks.

The auditory stimuli were recorded by a female native Dutch speaker and were normalized for volume using Praat (version 5.1, Boersma & Weenink, 2009).

Apparatus

The experiment was programmed using Presentation® (version 14.7, Neurobehavioral Systems, USA). The digit strings serving as loads and probes were presented in black lower case letters (Arial font size 48) against a white background on a 17-inch iiyama HM703UT monitor. Participants wore Sennheiser HD 280-13 300 Ω headphones and were seated in a sound-attenuated booth.

Procedure

Participants were tested individually and were instructed by the experimenter as well as by a standard set of instructions on the computer screen. The first experimental block was preceded by an annotated example and 40 practice trials. Participants were allowed to take short breaks after the practice block as well as between test blocks. Each of the 160 test trials consisted of three phases:

First, a string of digits (load) appeared for 2500 ms. Then, the participants heard a short sentence starting with *ik* ('I')[4] and one of the items from the word list for 2000 ms stimuli. The preceding digit string (load) was masked to avoid afterimage effects. The participants were instructed to make a lexical decision via two keys on a keyboard. Finally, another digit string followed by a question mark appeared on the screen, prompting the participants to indicate by pressing one of two keys if this was the same string as the one they saw at the beginning of the trial.

The experiment was quasi-self-paced; items disappeared after the first response. There was no feedback on accuracy. Each session including initial introduction and final debriefing took approximately 45 minutes. Figure 1 shows one high-load/nonword trial.

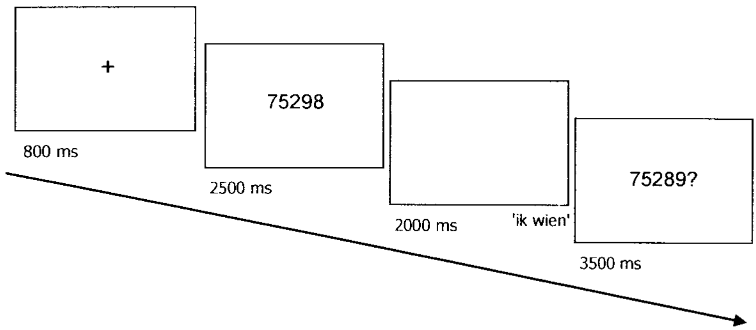

Figure 1: After the fixation cross, participants saw the digit load for 2500 ms. Then they made a lexical decision on a phrase starting with *ik* followed by an existing Dutch word or a nonword. Finally, the probe appeared.

[4] In pilot tests, participants reported confusion when they had to make a lexical decision on a verb in isolation. We added the grammatically adequate pronoun *ik* ('I') to embed the critical word in a syntactic context.

Results

Excluded data

59 native speakers of Dutch rated all forms in a list in an offline lexical decision task. Eight overregularized nonwords were excluded because they were accepted by more than 20% of people as an existing word of Dutch (*fluitte*, *bergde*, *graafde*, *meette*, *nijgde*, *strijdde*, *strijkte*, *windde*). Two target items were excluded because each was rejected by more than 20% of people (*morde*, *zwol*). Two nonwords were previously undetected past tense doublets (i.e., verbs with a regular as well as an irregular past-tense form, in the present study: *schuilde/schold*, *krijste/krees*). They were excluded as previous studies indicate that doublet regulars (e.g., *dived/dove*) are likely to be stored in the memory instead of being computed online (Ullman, 1993). Two nonwords appeared to be existing words of Dutch (*schal*, *zwier*). Two items were excluded due to errors in the programming of the experiment (*hijg*, *hijgde*).

Nine naïve Dutch native speakers rated the recorded auditory stimuli. In addition to giving a lexical decision, the raters were asked to write down which word they thought they heard. This was done to avoid possible confusion of phonologically identical inflections of different verbs, especially due to word-final devoicing of obstruents in Dutch and homophonous diphthongs like *ij/ei* [ɛɪ̯] (e.g., *leide* 'led' and *lijde* 'suffered' as well as *meed* 'avoided' and *meet* 'measure' are homophones). Based on these ratings, six items (*smeet*, *schaat*, *mad*, *leid*, *leidde*, *meed*) were excluded from further analyses. Additionally, *vil*, *vilde*, and *vroor* were excluded because they yielded accuracy rates below 50%. In total, 24 items (six target items) were excluded from all further analyses.

Finally, trials with reaction times longer than 2.5 SDs or shorter than 300 ms were discarded on a per-subject basis as were trials with incorrect lexical decisions. An average of 33 target items (out of 40, $SD = 3.9$) per participant were included in the analyses. No participants were excluded.

All analyses are based on log-transformed reaction times, which were measured from verb onset. We measured reaction times from both verb onset and verb offset and found comparable results. It is noteworthy, however, that measuring reactions from word offset leads to artificially decreased reaction times for past-tense forms compared to present-tense forms. Regular past-tense forms in Dutch contain the suffix *-[d/t]e*, while the bare stem itself is identical with the singular present-tense form. Upon hearing *maak*, a participant does not know if [k] marks the end of the stimulus *maak* or if the past tense suffix will follow, resulting in *maak-te*. They have to wait for the silence following the item and marking the word boundary. However, upon hearing the vowel [ə] in past-tense forms such as *maakte*, participants could infer that this signals the end of the word. Similarly, as some of the nonwords were overregularized irregular forms such as **hangde* or **roepte*, participants could not be sure that an irregular present-tense form might not end up being a nonword item. In order to avoid this artifact, all lexical decisions are reported as verb onset reaction times. (See Goodman and Huttenlocher (1988) and Marslen-Wilson (1990) for discussions on how to measure lexical decisions for auditory stimuli.)

Lexical status significantly influenced reactions, participants were faster to react to existing words (1167 ms) than to nonwords (1208 ms), $t = 2.11$, $p = .035$.

For existing words, we performed Linear Mixed Effects Models, using the languageR package (Baayen, 2007) and the lme4 package (Bates, 2005; R Development Core Team, 2011). With backwards elimination, we established the model that best explains reaction times on the basis of the independent factors of the items (regularity, form frequency, lemma frequency, load) and the subjects (age). Random factors were subjects and items. The fixed factors were centered. Due to the high correlation between lemma frequency and form frequency in our items ($r = .7$), we regressed form frequency from lemma frequency and used the residuals as a measure of form frequency to avoid collinearity. This ensures that form frequency effects reported here are free from confounding influences of lemma frequency.

Table 1: Factors included in the model that best explains onset reaction times.

Fixed Factors	β	Standard Error	t-value	p[5]
Intercept	7.1226	0.0397	179.54	< .001
age	-0.1757	0.0453	-3.88	< .001
lemma frequency	-0.1059	0.0412	-2.57	< .05
form frequency	-0.1687	0.0507	-3.33	< .001
form frequency : age	-0.1029	0.0441	-2.34	< .05
lemma frequency : age	0.0684	0.0344	1.99	< .05
regularity : age	0.0619	0.0228	2.73	< .01
regularity : form frequency : age	0.2422	0.0581	4.17	< .001

Random Factors	Name	Variance explained	Standard Deviation
verb	intercept	0.004371	0.066114
subject	intercept	0.017358	0.131748
Residual		0.022542	0.150140

There were main effects of lemma frequency ($\beta = -0.10585$, $t = -2.57$) and of form frequency ($\beta = -0.16862$, $t = -3.33$); people were faster to respond to high-frequency than to low-frequency words.

[5] P-values are based on the upper bound for the degrees of freedom (number of observations – number of fixed-effect parameters), see Baayen, Davidson, and Bates (2008).

A main effect of age revealed that the older age group showed longer reaction times than the younger age group (1284 ms vs. 1137 ms, β = -0.17567, t = -3.88). Age interacted with lemma frequency; the effect of lemma frequency on reaction times was stronger for older people (β = -0.10393) than for younger people (β = -0.03992), t = -1.99. Age interacted with form frequency; again, the effect of form frequency was stronger for older people (β = -0.20320) than for younger people (β = -0.27063), t = 2.73.

Age interacted with regularity; there was a significant effect of regularity for younger people (t = -2.73) but not for older people (t < 1). A three-way interaction between age, regularity and form frequency (t = 4.17) indicates differences in the interaction between regularity and form frequency between younger and older people.

In order to investigate the effects of age more closely, we established the model for each of the two age groups that best explains responses on the basis of the independent factors of the items (regularity, form frequency, lemma frequency, load).

Table 2: Factors included in the model that best explains onset reaction times of younger people.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.9474	0.0361	192.35	< .001
regularity	0.0742	0.0272	2.73	< .01
form frequency	-0.2706	0.0511	-5.29	< .001
form frequency : regularity	0.1863	0.0679	2.74	< .01

Random Factors	Name	Variance explained	Standard Deviation
verb	intercept	0.0036772	0.06064
subject	intercept	0.0107954	0.10390
Residual		0.0261044	0.16157

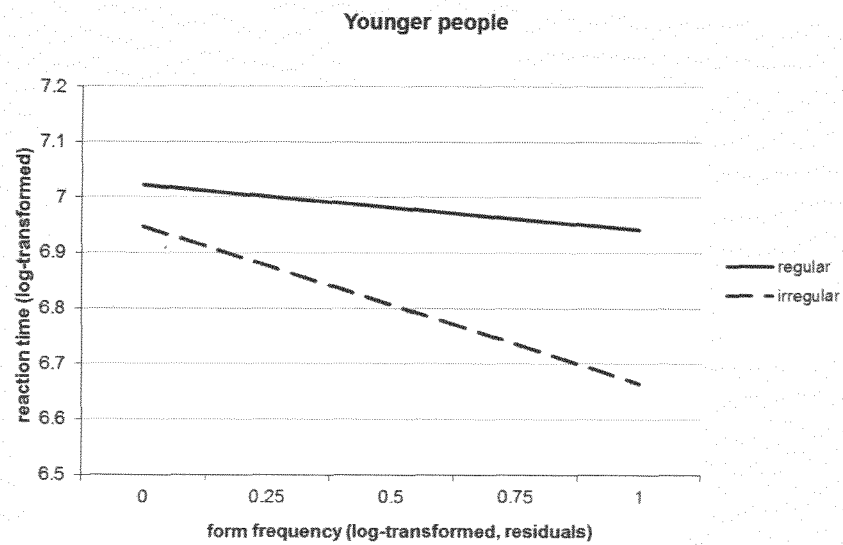

Figure 1: Regression line of the reaction times of younger people to regular and irregular past-tense forms. There is a significant interaction between regularity and form frequency ($t = 2.74$); reactions to irregular forms are subject to form frequency effects, while reactions to regular forms are not.

Table 3: Factors included in the model that best explains onset reaction times of older people.

Fixed Factors	β	Standard Error	t-value	p
Intercept	7.1282	0.0398	178.99	< .001
form frequency	-0.2032	0.0351	-5.79	< .001
lemma frequency	-0.1039	0.0427	-2.43	< .05
Random Factors	**Name**	**Variance explained**	**Standard Deviation**	
verb	intercept	0.0055905	0.07477	
subject	intercept	0.0242381	0.15569	
Residual		0.0186708	0.13664	

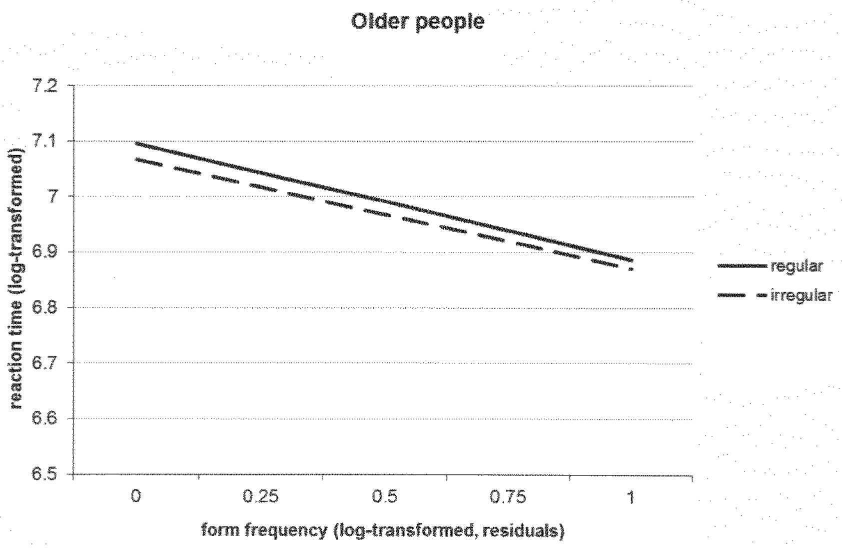

Figure 2: Regression line of the reaction times of older people to regular and irregular past-tense forms. There are effects of form frequency for both regular and irregular forms.

For younger people, there were significant main effects of form frequency (β = -0.27063, t = -5.29) and of regularity (regular: 1153 ms, irregular: 1121 ms, t = -2.73). Further, form frequency interacted with regularity (t = 2.74); that is, form frequency influenced reaction times for irregular forms (t = -5.086) but not for irregular past-tense forms (t = -1.57).

For older people, there was a main effect of form frequency (β = -0.20320, t = -5.79) and a main effect of lemma frequency (β = -0.10393, t = -2.43). Importantly, form frequency did not interact with regularity (t < 1). That is, form frequency influenced reactions to regular (t = -3.48) as well as irregular (t = -3.85) past-tense forms. There were no significant effects of the load manipulation.

Discussion of Experiment 1

The main effects largely correspond to our hypotheses as previously reported. Frequency is a powerful predictor for reaction times. The more often a word is encountered in a person's environment, the easier it becomes to recognize, as shown in previous studies (see e.g. Prasada & Pinker, 1993).

Further, age interacted with regularity and form frequency; only younger participants showed the expected regularity-by-form-frequency interaction, suggesting that they process regular and irregular verbs differently. Older participants, on the other hand, showed a frequency effect for all forms regardless of regularity, suggesting that they access both kinds of inflections in a similar manner (further evidenced by the absence of a main effect of regularity), namely by stronger reliance on a storage-based process.

The absence of a main effect of load was unexpected, especially given that similar kinds of dual tasks have proven to influence accuracy and latency on concurrently performed tasks. One might argue that our load manipulation did not strain cognitive resources to a sufficient degree. However, the accuracy of responses to the digit probe showed a significant effect of load, $t(47) = 8.73$, $p < .001$; participants were less accurate to remember five digits (83.1%) than two digits (92.6%). The reason behind the absent load effect may be the difference in modalities involved in the two processes (remembering a visually presented number vs. making a lexical decision on an auditorily presented word). It is possible that the two tasks did not interfere with each other, but instead used different cognitive resources. Evidence for modality-specific processing of working memory stimuli has been found in neuroimaging studies. Crottaz-Herbette, Anagnoson, and Menon (2004) asked participants to perform a 2-back task on either visually or binaurally presented digits and found that the tasks elicited activation in distinctly different areas. This finding is in line with a number of lesion studies indicating modality differences in short term memory processing (Warrington & Shallice, 1969; Warrington & Shallice, 1972; Shallice & Warrington, 1977; Basso, Spinnler, Vallar, & Zanobio, 1982; Penney, 1989). The involvement of different neural substrates might then explain the absence of a load effect in our experiment.

For this reason, we conducted a visual version of our experiment in order to make the two tasks involved in the dual-task situation as similar as possible. Targeting closely related structures and processes, we expected a visual working memory task to use the same cognitive resources that are required for a visual lexical decision task, resulting in a more pronounced load effect.

Experiment 2

Method

Participants

The experiment was conducted with 48 native speakers of Dutch (27 female, 7 left-handed, $M_{Age} = 32$, $range_{Age} = 18\text{-}71$). The younger age group ($N = 29$, 21 female, $M_{Age} = 23$, $range_{Age} = 18\text{-}35$) consisted of 29 participants, the older age group ($N = 19$, 13 female, $M_{Age} = 59$, $range_{Age} = 47\text{-}71$) of 19 participants. Of the younger people, 24 participants were university students or graduates, 4 participants underwent technical or vocational training, and 1 participant indicated secondary education as his or her highest educational level. Of the older people, 3 participants were university students or graduates, 14 participants underwent technical or vocational training, and 2 participants indicated secondary education as their highest educational level.

All participants stemmed from the participant pool of the Max Planck Institute for Psycholinguistics, reported having normal or corrected-to-normal vision, and were paid for their participation. All participants provided informed consent to participate in the study and all data were analyzed anonymously.

Materials

The target items, filler items and nonwords were identical to the ones used in the first experiment, comprising two lists of 160 items, with form frequency (continuous), lemma frequency (continuous), load (low – high) and regularity (regular – irregular) as within-subjects factors and age (continuous) as between-subjects factor. See Table A1 in the appendix for a complete list of target items and Table A2 for the nonwords.

Apparatus

The experiment was programmed using Presentation® (version 14.7, Neurobehavioral Systems, USA). All stimuli were presented in black lower case letters (Arial font size 48) against a white background on a 17-inch iiyama HM703UT monitor. Participants were seated in a sound-attenuated booth.

Procedure

The procedure was similar to the one used in the first experiment. The only difference was that in the second phase, participants saw the lexical decision stimuli on the screen instead of hearing them through headphones. All other parts of the experiment remained the same. Each session including initial introduction and final debriefing took approximately 30 minutes. Figure 4 shows one high-load/target trial.

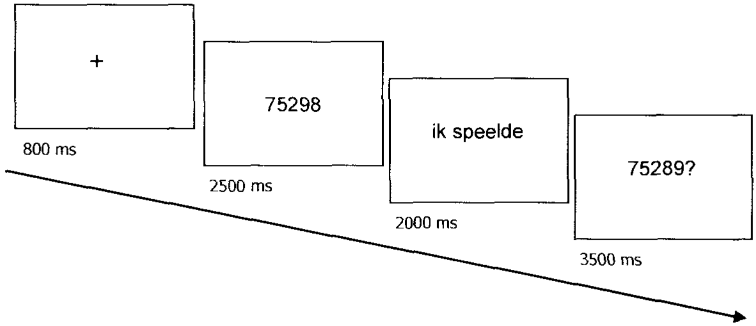

Figure 4: After the fixation cross participants saw a 2- or 5-digit number for 2500 ms. Then they were asked to make a lexical decision on a phrase starting with *ik* followed by either an existing Dutch word or a nonword. Finally, the probe appeared

Results

We excluded the items that were excluded from Experiment 1 as well as trials with reaction times longer than 2.5 SDs or shorter than 300 ms to ensure comparability between the two experiments as much as possible. This resulted in the exclusion of 5.26% of the data. No participants were excluded.

The influence of lexical status on reaction times just failed to reach significance, participants were slightly faster to react to existing words (both targets and fillers, 1018 ms) than to nonwords (1056 ms), $t = 1.80$.

We performed the same analyses as in Experiment 1.

Table 4: Factors included in the model that best explains reaction times

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.9967	0.0473	147.94	< .001
age	-0.1473	0.0489	-3.01	< .01
lemma frequency	-0.0917	0.0402	-2.28	< .05
form frequency	-0.2404	0.0693	-3.47	< .001
regularity : age	0.1113	0.0392	2.84	< .01
regularity : form frequency : age	0.1686	0.0840	2.01	< .05

Random Factors	Name	Variance explained	Standard Deviation	Correlation	
verb	intercept	0.0048475	0.069624		
subject	intercept	0.0201824	0.142065		
	load	0.0051217	0.071566	-0.144	
	regularity	0.0048396	0.069567	-0.164	-0.364
Residual		0.0440829	0.209959		

There were main effects of form frequency (β = -0.24038, t = -3.47) and of lemma frequency (β = -0.09173, t = -2.28); people were faster to respond to high-frequency than to low-frequency words. Age acted again as a main effect; older people showed overall slower reactions (1141 ms vs. 1029 ms, t = -3.01). Secondly, age interacted with regularity and frequency (t = 2.01).

In order to investigate the effects of age, we established the model for each of the two age groups that best explains the results on the basis of the independent factors of the items (regularity, form frequency, lemma frequency, load).

Table 5: Factors included in the model that best explains onset reaction times of younger people.

Fixed Factors		β	Standard Error	t-value	p
Intercept		6.8339	0.0387	176.64	< .001
form frequency		-0.2615	0.0527	-4.96	< .001
lemma frequency		-0.0728	0.0401	-1.81	< .1
regularity		0.1399	0.0274	5.11	< .001
regularity : form frequency		0.2826	0.0689	4.10	< .001
Random Factors	**Name**	**Variance explained**	**Standard Deviation**		**Correlation**
verb	intercept	0.0028769	0.053637		
subject	intercept	0.0188567	0.137320		
	form frequency	0.0027836	0.052760		0.430
Residual		0.0539487	0.232268		

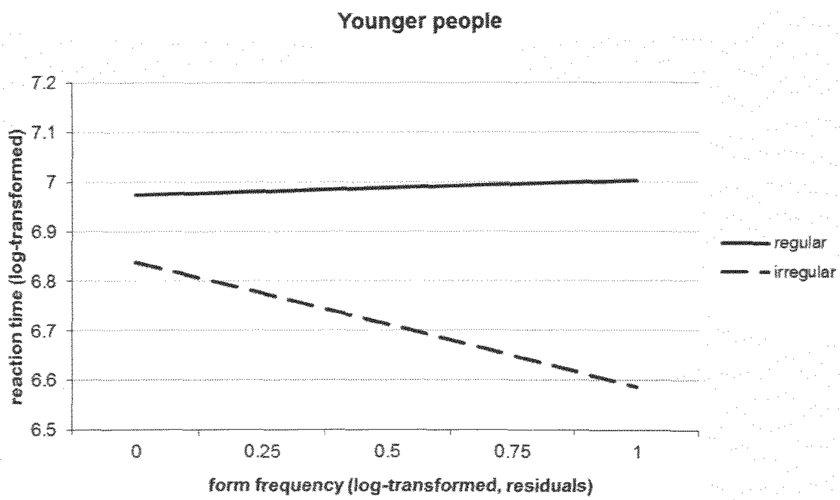

Figure 3: Regression line of the reaction times of younger people to regular and irregular past-tense forms. There is a significant interaction between regularity and form frequency (β = -0.20242, t = -3.07); reactions to irregular forms are subject to form frequency effects, while reactions to regular forms are not.

Table 6: Factors included in the model that best explains onset reaction times of older people.

Fixed Factors	β	Standard Error	t-value	p
Intercept	7.0076	0.0504	139.00	< .001
lemma frequency	-0.1318	0.0578	-2.28	< .05
form frequency	-0.2564	0.0745	-3.44	< .001

Random Factors	Name	Variance explained	Standard Deviation	Correlation	
verb	intercept	0.0069035	0.083087		
subject	intercept	0.0125789	0.112156		
	load	0.0055461	0.074472	-0.43	
	form frequency	0.0015542	0.039424	0.77	0.25
Residual		0.0334252	0.182826		

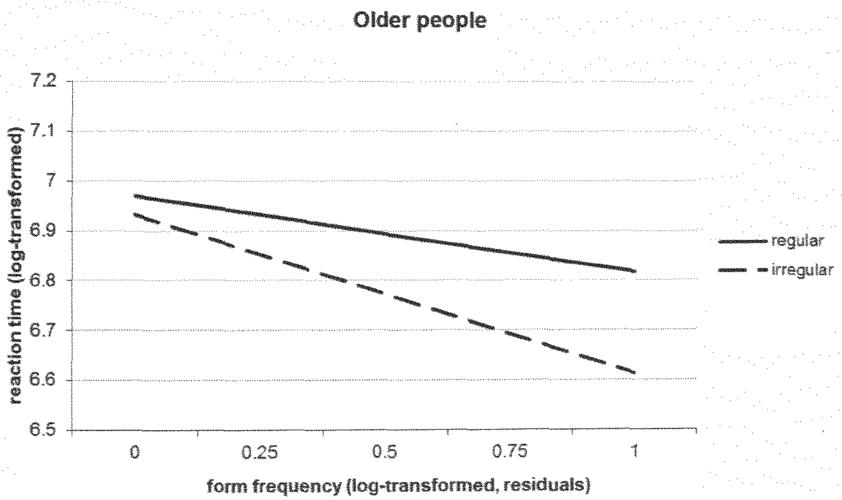

Figure 4: Regression line of the reaction times of older people to regular and irregular past-tense forms. There are effects of form frequency for both regular and irregular forms, but no interaction between regularity and form frequency.

The results mirror the findings of Experiment 1. For younger people, the main effect of lemma frequency was marginally significant (β = -0.07280, t = -1.81). Form frequency acted as a main effect factor (β = -0.26146, t = -4.96). However, the interaction between form frequency and regularity revealed that facilitating effect of form frequency applies only to irregular items (t = -5.12) but not to regular verbs ($t < 1$).

As in Experiment 1, for older people, there was a main effect of form frequency (β = -0.25640, t = -3.44) but no interaction between form frequency and regularity. Instead, form frequency influenced reactions to regular as well as irregular forms.

While the effects of load were stronger in this visual version of our lexical decision experiment, they did not significantly influence reaction times.

Discussion of Experiment 2

The findings in Experiment 2 replicated a number of the effects found in the first experiment. High form frequency and high lemma frequency facilitated lexical decisions, resulting in shorter reaction times for high-frequency verbs.

As in Experiment 1, we found an interaction between form frequency, regularity, and age. For younger participants, the effect of frequency does not affect all kinds of verb forms to the same extent. While high form frequency facilitates the recognition of irregular verbs, it has no effect on the processing of regular past-tense forms for younger people. For older participants, there was no interaction between regularity and form frequency; instead, high frequency led to faster reaction times for regular forms as well as irregular forms.

General discussion

In the present study, we investigated the influence of age and working memory load on morphological processing of regular and irregular words. In both auditory and visual lexical decision, we found an interaction between age, form frequency, and regularity. For younger people, form frequency influenced lexical decisions for irregular forms but not for regular forms. For older people, form frequency influenced reaction times for regular as well as irregular forms. As effects of form frequency are taken as an indicator of storage, this indicates that younger people decompose regular forms into their constituent morphemes, while older people access these forms as whole words.

The interaction found for younger people is in line with predictions made by dual-route models (see e.g. the dual-route model by Pinker and Prince, 1994; the words-and-rules theory by Pinker and Ullman, 2002; or the augmented addressed morphology model by Caramazza, Miceli, Silveri, and Laudanna, 1985). Figure 5 demonstrates the process that offers an explanation for our findings.

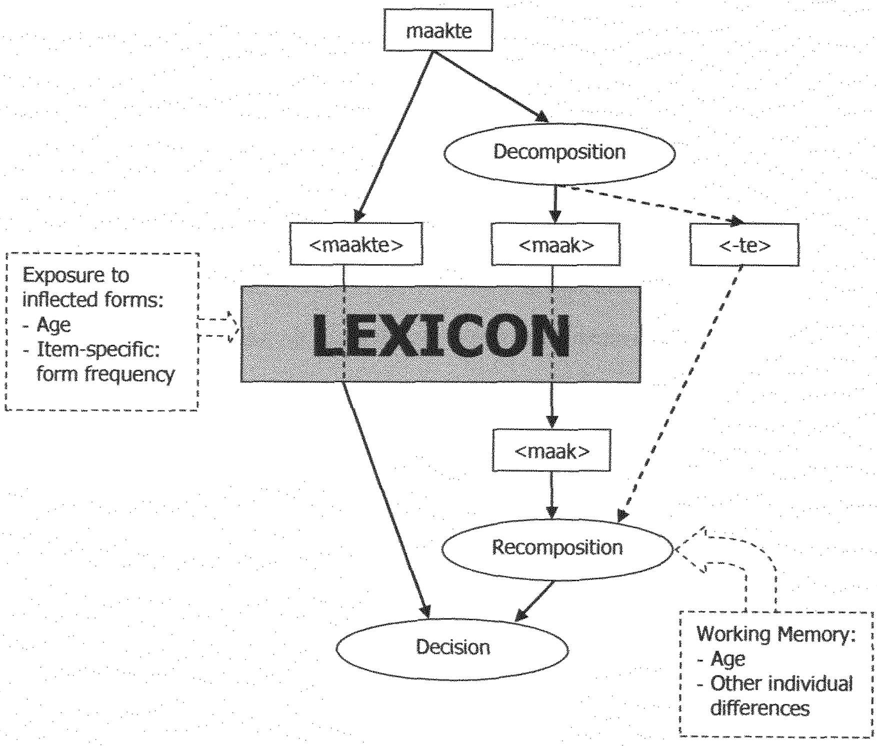

Figure 5: A model of the parallel two-mechanism process of morphologically complex inflected words.

When reading a word, obligatory decomposition into as many morphemes as possible occurs. Evidence for such an obligatory decomposition process has been reported in clinical studies (Tyler et al., 2002) as well as experimental work (Caramazza et al., 1988; Rastle & Davis, 2008). After decomposition, the comprehension system identifies the stem of the form which is subsequently looked up in the mental lexicon. Upon finding an appropriate entry in the lexicon, this entry is checked for its regularity feature. If the lemma carries a [+regular] feature, it is accepted as the correct form, leading to a positive 'word' decision. As this process of decomposition is time-consuming, any effects of stem frequency that might have led to faster reactions of monomorphemic regular forms have disappeared by the time the lexical decision is made. At the same time, the whole form is also looked up in parallel in the lexicon.

There are a number of factors that can influence which of the two routes wins out and will be the first to lead to a lexical decision on a morphologically complex form. For younger people, this whole form is usually not of sufficient frequency to be found before the decompositional route has made a decision. Previous exposure, either on an item basis (i.e., frequency) or on a subject basis (e.g., higher age), changes the structural organization of the mental lexicon, such that inflected forms are easier to recognize. Irregular forms, on the other hand, cannot be decomposed, so they are directly subject to form frequency effects.

On the decompositional side, the computational process might be influenced by working memory differences; in line with the claims of full-listing accounts, the process of maintaining several morphemes in the cognitive system is costly. Working memory abilities are known to decline with age (Dobbs & Rule, 1989; Salthouse, 1991; Salthouse & Babcock, 1991). We would then also predict an effect of age on accuracy of number retention in our experiment. However, there were no age differences in performance; older people were as good as younger people at recognizing the number string in the probe phase. It seems unlikely that working memory differences were the reason for the apparent processing differences.

Lastly, one might propose that the age effect is a mere confound with the educational level of our participants. The group of younger participants was largely homogenous, made up of university students. The older participants, on the other hand, came from a broader range of educational backgrounds. However, it should be noted that all participants were contacted in English, so they possessed working knowledge of a second language, implying a certain degree of formal schooling. Yet, we cannot entirely exclude the possibility that differences in education and related differences in metalinguistic knowledge between the two age groups are at the basis of the differences in reaction times.

It seems that the most likely explanation for the apparent age differences on the processing of regular vs. irregular verbs is differences in exposure, leading to differences in their mental lexicon. As mentioned earlier, it is plausible that more encounters with fully inflected forms render these easier to recognize, which in turn leads the storage-based route to be faster than the decompositional route. At first glance, it then seems surprising that lexical decisions of older participants are slower compared to those of younger participants. Having encountered a much higher number of types and tokens, one might expect faster reactions for older participants. However, the main effect of age on reaction times replicates findings of previous research showing that older participants are slower overall in lexical decision tasks (Allen et al., 1991; Ratcliff, Thapar, Gomez, & McKoon, 2004). Ratcliff and colleagues investigated this phenomenon further and explained the age effect by way of applying the diffusion model for two-choice decisions (Ratcliff, 1978, 1988; Ratcliff & Rouder, 1998) to lexical decision data. This model separates the rate of accumulation of evidence (*drift rate*, level of 'wordness') from the decision criterion and from nondecision components of processing. It is able to explain the age effect which had already been observed in previous studies (Spieler & Balota, 2000; Revill & Spieler, 2012; Balota, Cortese, Sargent-Marshall, & Yap, 2004; Balota & Ferrano, 1996). Ratcliff et al. (2004) reported that older participants adopted a more conservative criterion for their decision and were 80-100 ms slower in the nondecision component of the reaction to lexical stimuli. That is, the part that is most responsible for age differences in lexical decisions is of a more general processing speed nature, comprising of perceptual and encoding processes and response execution. This process is independent from the size of the mental lexicon against which the lexical input is compared. There were no age differences for the drift rate. Thus, it comes as no surprise that the older participants in our experiment showed slower reaction times, despite our claim that lifelong exposure leads to faster reactions to full forms. It is also noteworthy that studies investigating the relationship between measures of vocabulary size and reaction times in lexical decisions showed only a modest facilitatory effect of a large vocabulary (Katz et al., 2012).

The motivation for these experiments was two-fold. First, we aimed to investigate the influence of cognitive load on the comprehension of verbs. We hypothesized that working memory influences the computational process of regular morphology. However, the load manipulation in our experiment did not influence reaction times. A possible explanation for this may be relative ease of the task as indicated by very high recall accuracy rates. Even so, it is noteworthy that our participants made significantly more mistakes recognizing longer load digit strings compared to shorter digit strings (accuracy in Exp. 2: 91.2% for five digits vs. 95.1% for two digits, $t = -2.96$, $p = .003$), indicating that the high load condition was indeed more difficult, even if it did not interfere with the comprehension process necessary for lexical decisions.

Rastle and Davis (2008) offered an account of visual word recognition according to which morphological decomposition happens early, on a sublexical level. Studies on masked priming have often found no difference between priming effects for transparently related words (e.g., *dark* primes *darkness*) and priming effects for apparently related words (e.g., *corn* primes *corner*). However, both of these kinds of priming lead to more facilitation than a mere form overlap (e.g., *broth* priming *brothel*) does, indicating that morphological decomposition is a rapid and obligatory process if the orthographic form suggests a polymorphemic status of the word[6]. That is, *-er* is a morpheme commonly used to turn verbs into agent nouns (*hunt* + *-er* = *hunter*), suggesting a possible relationship between *broth* and *brother*. Both masked transparent relation priming and masked apparent relation priming lead to facilitation effects of similar size, despite the fact that *–er* is usually not affixed onto nouns. The authors took this as evidence for the early locus of this process. In this light, it is possible that the decomposition process happens too early and too automatically to be affected by the load manipulation in any costly manner. Instead, cognitive load might influence processes on a higher stage of the comprehension process. Tasks requiring a deeper semantic comprehension of the material could be more sensitive to a manipulation of cognitive processing load.

Our second goal was to address age as a possible factor influencing the comprehension process. Indeed, older people showed a response pattern different from that of young people; instead of an interaction between regularity and frequency, their reactions to regular verbs seemed similar to their reactions to irregular verbs, leading to the conclusion that they process both kinds of inflectional morphology in a similar manner. We suggest accumulated exposure (as a subject-based equivalent to form frequency) as a likely explanation. To the best of our knowledge, aging research has not investigated systematic differences in the processing of morphemes, so our explanations for the reasons behind these differences remain speculative.

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[6] See e.g. Kazanina, Dukova-Zheleva, Gerber, Kharlamov, and Tonciulescu (2008); Marslen-Wilson, Bozic, and Randall (2008), McCormick, Rastle, and Davis (2007), Diependaele, Sandra, and Grainger (2005); Rastle, Davis, and New (2004); Longtin, Segui, and Hallé (2003); Rastle and Davis (2003); Rastle, Davis, Marslen-Wilson, and Tyler (2000); and Feldman and Soltano (1999).

Appendix

Table A1: List of items by regularity, incl. gloss and log-transformed lemma and form frequency of the past-tense form.

Infinitive	Item	Frequency		Average RT (in ms)		Average accuracy		Gloss
		Lemma	Form	Auditory	Visual	Auditory	Visual	
Regular								
beven	beefde	7.23	5.80	1195	1208	0.96	0.95	to tremble
blozen	bloosde	6.53	5.63	1170	1088	1.00	1.00	to blush
dulden	duldde	6.46	4.73	1134	1187	0.92	0.95	to endure
glippen	glipte	6.03	5.21	1269	1061	1.00	0.96	to slip
gloeien	gloeide	6.91	5.29	1323	1071	1.00	1.00	to glow
gooien	gooide	8.43	7.38	1428	1180	1.00	1.00	to fling
hijgen	hijgde*	7.31	6.04	---	---	---	---	to pant
hink	hinkte	5.55	4.34	1228	1025	0.87	0.96	to limp
huilen	huilde	8.43	5.12	1129	1054	1.00	0.96	to howl
kauwen	kauwde	6.54	5.12	1195	1189	1.00	0.95	to chew
kennen	kende	9.98	8.44	1217	1240	1.00	0.91	to know
leiden	leidde*	9.30	7.70	---	---	---	---	to lead
leunen	leunde	7.64	7.10	1157	1055	1.00	1.00	to lean
leven	leefde	10.19	7.53	1236	1181	1.00	1.00	to live
maken	maakte	11.37	9.58	894	1012	0.96	1.00	to make
melden	meldde	7.49	6.16	1221	1028	0.83	1.00	to report
mengen	mengde	7.07	5.06	1260	1201	1.00	1.00	to mix
morren	morde*	5.43	3.14	---	---	---	---	to grumble
naaien	naaide	6.12	3.97	1228	1100	1.00	0.95	to sew
richten	richtte	9.02	7.48	1094	990	1.00	1.00	to aim
rillen	rilde	6.43	5.55	1146	1044	0.96	1.00	to shiver
roeien	roeide	6.29	4.37	1304	1072	1.00	1.00	to row
schudden	schudde	8.56	8.18	1186	1097	0.96	1.00	to shake
spelen	speelde	9.69	7.91	1156	996	1.00	1.00	to play
spreiden	spreidde*	7.15	6.08	---	---	---	---	to spread
storen	stoorde	7.24	5.11	1441	1041	0.96	1.00	to disturb
strelen	streelde	7.58	6.88	1312	1087	1.00	0.96	to stroke
trachten	trachtte	8.41	7.00	1084	1115	0.88	0.91	to attempt
turen	tuurde	6.68	5.95	1313	1085	0.92	0.90	to peer
villen	vilde*	4.73	1.79	---	---	---	---	to skin
voelen	voelde	10.28	9.54	1166	1037	1.00	1.00	to feel
volgen	volgde	9.99	7.97	1290	995	0.85	1.00	to follow
vullen	vulde	8.08	6.72	1285	1169	0.96	1.00	to fill
waken	waakte	6.57	4.41	1306	1089	0.96	1.00	to wake
wekken	wekte	8.06	6.29	1119	1132	0.95	0.96	to wake
wenden	wendde	7.87	7.24	1136	1174	1.00	1.00	to turn
weven	weefde	5.58	2.56	1408	1251	0.82	0.60	to weave
wonen	woonde	9.11	7.70	1373	1233	1.00	0.91	to reside
zwaaien	zwaaide	7.76	6.89	1325	957	0.96	0.96	to wield
zwenken	zwenkte	5.18	4.69	1461	1034	0.82	0.95	to turn
Irregular								
blijven	bleef	10.87	9.63	1096	924	0.91	1.00	to stay
blinken	blonk	6.50	4.90	1225	1042	0.78	0.94	to shine
brengen	bracht	10.51	8.86	1232	991	1.00	1.00	to bring
dragen	droeg	9.39	8.31	1021	972	0.96	0.96	to carry
drijven	dreef	8.12	6.79	1084	994	0.91	0.96	to float
drinken	dronk	8.82	7.42	985	857	1.00	1.00	to drink

* Excluded items

Infinitive	Item	Frequency Lemma	Frequency Form	Average RT (in ms) Auditory	Average RT (in ms) Visual	Average accuracy Auditory	Average accuracy Visual	Gloss
druipen	droop	6.56	5.56	1294	1430	0.55	0.86	to drip
glijden	gleed	8.07	7.14	1203	1095	1.00	0.96	to slide
glimmen	glom	7.02	5.21	1177	1062	0.82	0.91	to glimmer
grijpen	greep	8.33	7.24	1136	878	0.96	0.92	to grasp
heffen	hief	7.73	7.00	1239	1110	0.54	0.86	to lift
helpen	hielp	9.37	7.33	1140	1011	1.00	1.00	to help
houden	hield	10.75	9.48	1102	934	0.96	0.96	to hold
klinken	klonk	9.00	8.35	1090	1099	0.94	0.96	to sound
kruipen	kroop	7.95	6.93	1015	941	0.96	0.96	to crawl
liegen	loog	7.35	5.63	1161	918	1.00	1.00	to lie
mijden	meed	5.61	3.81	1434	1389	1.00	0.87	to avoid
nemen	nam	10.69	9.40	1108	1037	1.00	0.96	to take
rijgen	reeg	4.91	2.64	1180	1199	0.71	0.91	to string
schelden	schold	6.49	5.15	1223	1048	0.93	1.00	to scold
schenden	schond	5.42	2.71	1459	1238	0.81	0.67	to violate
schrijden	schreed	5.40	4.68	1427	1249	0.78	0.94	to stride
smijten	smeet	6.85	5.99	1361	1112	1.00	0.92	to hurl
spreken	sprak	10.13	8.71	1152	970	1.00	1.00	to speak
stinken	stonk	6.97	5.64	1128	986	1.00	1.00	to stink
stuiven	stoof	6.00	1.39	1369	1119	0.68	0.83	to dash
treffen	trof	8.25	6.86	1105	885	0.96	0.96	to encounter
vreten	vrat	6.32	4.52	1328	1212	0.96	1.00	to eat
vriezen	vroor	6.18	4.51	1329	1143	0.96	0.72	to freeze
wegen	woog	7.19	5.77	1165	1021	1.00	1.00	to weigh
werpen	wierp	8.49	7.72	1296	1017	0.93	1.00	to throw
winnen	won	8.13	6.24	1048	1080	0.91	0.96	to win
wrijven	wreef	7.61	6.91	1391	995	1.00	0.91	to rub
zenden	zond	7.47	6.12	1483	1070	0.60	0.88	to send
zingen	zong	8.35	6.74	1142	1019	1.00	1.00	to sing
zuigen	zoog	7.18	5.98	1155	1147	1.00	0.91	to suck
zuipen	zoop	5.47	3.56	1211	1218	0.92	0.83	to drink
zwellen	zwol*	6.51	4.91	---	---	---	---	to swell
zwemmen	zwom	7.36	5.48	1250	976	1.00	0.96	to swim
zwerven	zwierf	6.54	5.04	1203	1130	1.00	0.96	to wander

Table A2: List of nonwords, incl. infinitive, original simple past form, and log-transformed lemma and form frequency of the SP form

Overregularized Forms				
Infinitive	Original irregular SP form	Overregularized form	Frequency (log-transformed) Lemma	Frequency (log-transformed) Form
bergen	borg	bergde*	6.52	5.17
blijken	bleek	blijkte	9.88	8.85
dwingen	dwong	dwingde	8.15	6.53
fluiten	floot	fluitte*	7.00	5.79
graven	groef	graafde*	6.48	4.37
hangen	hing	hangde	9.37	8.28
kiezen	koos	kiesde	8.93	6.82
knijpen	kneep	knijpte	7.30	6.69
krijsen	krees	krijste*	6.40	0.00
meten	mat	meette*	7.37	5.51
nijgen	neeg	nijgde	4.20	3.09
rijden	reed	rijdde	9.06	7.95
roepen	riep	roepte	9.62	9.02
schuilen	school	schuilde*	7.04	5.15

spijten	speet	spijtte	7.80	5.54
strijden	streed	strijdde*	6.74	4.09
strijken	streek	strijkte*	7.21	6.30
trekken	trok	trekte	9.91	9.11
vallen	viel	valde	10.17	9.01
winden	wond	windde*	6.12	4.84
zinken	zonk	zinkte	6.67	5.55

Pseudo-irregulars

Infinitive	Original irregular SP form	Vowel-changed form	Frequency (log-transformed) Lemma	Form
duiken	dook [do:k]	deek [de:k]	7.58	6.68
melken	molk [mɔlk]	malk [mɑlk]	5.17	2.83
prijzen	prees [pre:s]	praas [pra:s]	6.89	5.39
rieken	rook [ro:k]	reek [re:k]	5.17	0.00
roepen	riep [rip]	roop [ro:p]	9.62	9.02
schijnen	scheen [sɣe:n]	schaan [sɣa:n]	9.19	8.37
smelten	smolt [smɔlt]	smalt [smɑlt]	6.70	4.61
sterven	stierf [stirf]	storf [stɔrf]	8.78	7.13
treden	trad [trɑt]	troed [trut]	8.49	6.78
vangen	ving [vɪŋ]	vong [vɔŋ]	8.14	6.15
vechten	vocht [vɔxt]	vicht [vɪxt]	7.88	5.52
wijken	week [ʋe:k]	woek [ʋuk]	6.78	4.93
zweren	zwoer [zʋur]	zwier [zʋir]	6.61	4.88

Other nonwords

Items				
boof	lit	reek	smok	woen
brang	loed	reem	splots	wonk
daa	loen	riest	spraat	wuid
dricht	mad	rocht	stoch	zaa
foots	moen	roed	trif	zerg
geet	niem	rouk	vorf	zoerg
goof	pach	schaat	vroos	zwal*
hoel	plits	schal	wecht	
klocht	pous	schief	wien	
kriet*	proet	smalt	woeg	

The influence of pseudoword material on morphological processing

Chapter 3

Abstract

According to dual-route models, regular morphologically complex forms can either be retrieved from the mental lexicon as units or decomposed into their constituent morphemes. In earlier work, we found evidence suggesting that young people decompose regular inflected forms, whereas older people tend to retrieve them as units. The goal of the present study was to assess further how important whole-word access and decomposition are in different age groups. In a visual lexical decision experiment, we investigated whether participants could be encouraged to decompose complex forms by the presentation of different types of pseudowords. We used "easy" pseudowords (no morphological complexity, e.g. *plits*) as well as "difficult" pseudowords (e.g. overregularizations: *vangde* 'catched'). The two types of pseudoword were tested in separate sessions. The word targets were 40 regular and 40 irregular Dutch past-tense verb forms with a wide range of form frequency. We tested 24 younger (18-27 years) and 24 older (61-81 years) Dutch speakers.

Mixed-effects models yielded different results for younger and older participants. Younger people showed a 3-way interaction: in the difficult-pseudoword condition, there was an interaction of form frequency and regularity, but in the easy-pseudoword condition, there was only a main effect of form frequency. Assuming that a form frequency effect is indicative of whole-word retrieval, this pattern indicates that the younger participants decomposed the regular forms only in the presence of difficult pseudowords. In contrast, older participants only showed a main effect of form frequency, indicating that they retrieved the word forms as units, regardless of regularity and pseudoword type. We suggest that the relative efficiency of the two routes to regular forms – whole-word retrieval and decomposition – may change across the lifetime.

Models of word recognition traditionally fall into one of two categories with respect to the assumptions they make about regular morphological processing: single-route models and dual-route models. Single-route models, on the one hand, postulate that regular and irregular inflected words are accessed in a similar manner. Within this group of models, there are different theories about the nature of the stored items. Are the stored units whole words, as claimed by Butterworth (1983), or rather constituent morphemes (Taft, 1979, 2004)?

Dual-route models, on the other hand, assume the existence of two distinct mechanisms. One of these routes usually involves the computation of morphologically complex forms via decomposition into stem and affix. The other route is the direct access of fully inflected stored forms. Dual-route models differ as to whether these two routes are based in two distinct systems (e.g. the declarative/procedural model by Ullman, 2001a, 2001b, 2004) or whether they are two different processes rooted in one system (Frost, Forster, & Deutsch, 1997; Schreuder & Baayen, 1995). Further, models differ in the extent to which the two processes at work are in competition with each other (e.g. the morphological race model by Frauenfelder & Schreuder, 1992).

Measures of frequency have been used to address the question whether a single- or a dual-route model is the more appropriate explanation for morphological processing. Proponents of dual-route models back up their claims with studies that find an interaction between regularity and form frequency; irregular forms yield form frequency effects, while regular forms do not (Bybee & Slobin, 1982; Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995; Prasada, Pinker, & Snyder, 1990; Ullman, 1993; Seidenberg & Bruck, 1990; but see Daugherty & Seidenberg, 1992, 1994, Woollams, Joanisse, & Patterson, 2009; Tabak, Schreuder, & Baayen, 2010). These findings support the view of a fundamental distinction between regular and irregular inflections.

As memory traces get stronger with additional exposure, irregular forms stored in the lexicon will be subject to form frequency effects. Regular forms, however, are merely influenced by base frequency effects but not by form frequency effects, indicating that they are always computed anew (Bertram, Schreuder, & Baayen, 2000).

In two previous experiments with regular and irregular past-tense inflections, we found age differences in lexical decisions. While the younger student sample showed an interaction between form frequency and regularity, the older population did not. Instead, the older participants showed a form frequency effect for regular as well as irregular items. This finding indicates that younger people decompose polymorphemic words into their constituent morphemes, while older people rely more on retrieval of stored forms. An explanation for the age differences could be effects of lifelong learning. Over the course of their lifetime, people encounter a great number of inflected forms. This accumulated exposure may make older people more likely to process even regular inflections as whole words. This usage-based interpretation is supported by research showing that very high frequency regular verbs (Alegre & Gordon, 1999; Lehtonen & Laine, 2003; Stemberger & MacWhinney, 1986; Lehtonen, Niska, Wande, Niemi, & Laine, 2006) are indeed stored as whole forms. The assumption that older people follow a storage-based route led us to the question whether decomposition was still an option for older people, and whether it could be induced.

The influence of pseudowords

One method to influence people's processing is through different types of appropriate pseudowords. James (1975) reported that the pronounceability of pseudowords influenced the depth of semantic processing of target words. In a lexical decision experiment, he found the well-established effect of abstractness vs.

concreteness on target reaction times when pseudowords were pronounceable, but no difference between reaction times when pseudowords where unpronounceable. Depth of processing is argued to be dependent on the similarity of the distractors with the targets (LaBerge, 1971). Rendering the pseudowords unpronounceable led to more shallow semantic processing of the target words, as indicated by the absence of a concreteness effect. Similarly, Waters and Seidenberg (1985) reported greater use of phonological information of all items if the materials included difficult items (i.e., words with uncommon spelling and irregular pronunciation, e.g. *gauge*, *choir*, *aisle*).

Taft (2004) showed that similar effects can be found for morphological processing by manipulating the nature of the pseudoword. "Difficult" pseudowords (illegal combination of existing stem + existing affix, e.g. **joying*) yielded slower reactions to morphologically complex target forms than "easy" pseudowords (nonword stem + affix, e.g. **joxing*). The author argued that this difference is due to a deeper level of processing when pseudowords are difficult. Pseudowords that appear to be morphologically complex are decomposed, and their constituent morphemes are looked up in the mental lexicon. Upon deciding that both morphemes are existing forms, they are recombined to check whether their combination results in an existing and syntactically legal word. Only then the pseudoword is rejected. Easy pseudowords, on the other hand, can in principle be readily disregarded on the basis of the lexical status of their first morpheme, leading to faster reactions. In this manner, the nature of the pseudowords can influence the way in which morphologically complex words are processed.

Our previous work indicated that younger participants process regular forms via decomposition and irregular forms from their stored representations, while older participants did not distinguish between regular and irregular inflected verbs but access all of them as stored forms. However, in our previous experiment, we used only 25% "difficult" pseudowords (i.e. nonwords made up from the illegal combination of an existing stem and an affix, e.g. **brengde*, *'bring-ed') and 75% "easy" made-up words (i.e. phonologically legal letter strings of no seeming morphological make-up).

In the present study, we try to induce morphological processing via decomposition in an older sample by putting emphasis on the combinatorial stage in a similar manner to Taft (2004). When a participant recognizes that some of the items they encounter in an experiment consist of existing morphemes that are merely illegally combined, this may encourage them to process all forms more deeply. This is expected to lead to decomposition of regular target words. This way, we can gain more insights into the differences between younger and older people reported in Chapter 2. How consistent is whole-word access used by older people when the task is made difficult?

Our design included form frequency (continuous), lemma frequency (continuous), and pseudoword type (easy vs. difficult) as within-subjects factors and age (younger vs. older) as between-subjects factor. In the "difficult" condition, pseudowords were syntactically illegal combinations of an existing stem and an existing affix. This condition was thought to highlight the morphological complexity of the target words by putting special emphasis on the decomposition and recombination stage of regular morphological processing. This could encourage the older participants to process suffixed items via the decompositional route, leading to an interaction between regularity and form frequency in the difficult condition (i.e., a form frequency effect for irregular but not for regular items).

In the "easy" condition, on the other hand, pseudoword items were similar to the ones in our previous experiments, phonologically legal nonwords, mostly of no apparent morphological make-up. Here, we expected to replicate the findings from the previous experiments – that is, a form frequency effect for regular as well as irregular items for older people. To ensure comparability, we also tested a group of students for whom we did not expect differences in behavior. Table 1 summarizes the conditions and expected findings.

Table 1. Overview over the conditions and expected outcomes.

	Easy pseudowords	Difficult pseudowords
Young participants	frequency-by-regularity interaction → decomposition of regular verbs, storage-based access of irregular verbs	frequency-by-regularity interaction → decomposition of regular verbs, storage-based access of irregular verbs
Old participants	frequency effects for all items, no frequency-by-regularity interaction → Storage-based access for regular and irregular verbs	frequency-by-regularity interaction → decomposition of regular verbs, storage-based access of irregular verbs

The two conditions were presented in separate testing sessions. In the first session, all participants were tested in the difficult condition. In the second session, participants were tested in the easy condition. Both sessions were spaced out by at least three weeks to avoid potential long-term effects of the expected induction of decomposition.

Experiment 1

Method

Participants

The younger age group (18 female, 3 left-handed, $M_{\text{Age}} = 21$, $range_{\text{Age}} = 18\text{-}29$) and the older age group (16 female, 1 left-handed, $M_{\text{Age}} = 67$, $range_{\text{Age}} = 60\text{-}74$) consisted of 24 participants each.

Of the younger sample, 22 participants were university students or graduates and 2 participants had finished a technical or vocational training. Of the older sample, 7 were university graduates, 16 had finished technical or vocational training, and 1 indicated secondary education as his or her highest educational level.

All participants stemmed from the participant pool of the Max Planck Institute for Psycholinguistics, reported having normal or corrected-to-normal vision, and were paid for their participation. All participants provided informed consent to participate in the study and all data were analyzed anonymously.

Materials

The stimuli consisted of 100 existing Dutch words and 100 pseudowords.

Target and filler items:

Of the existing words, 80 items were verbs (40 regular past-tense forms and 40 irregular past-tense forms)[7]. These were matched for log-transformed lemma frequency and form frequency of their past-tense form as reported in CELEX (Baayen, Piepenbrock, & Gulikers, 1995), $t(78) < 1$, *ns* (for both lemma frequency and form frequency). While the items of interest were the past-tense singular forms of the verbs (target items)[8], we included present-tense singular inflections (filler items).

[7] The 80 target words were identical to the ones used in Chapter 2

[8] The *Onvoltooid Verleden Tijd* (lit. 'Unfinished Past Tense') of weak/regular verbs in Dutch is formed by adding *de(n)* or *te(n)* onto the stem, leading to *werkte* ('worked') and *volgde* ('played'), respectively. Strong/irregular verbs show a variety of changes from the stem of the present-tense infinitive form to the stem of the past-tense form, e.g. ablauting (*bieden* *bood*, 'to offer') and consonantal alternation (*kopen* - *kocht*, 'to buy').

The items were randomly assigned to one of two lists, so that no present-tense form of a given verb appeared in the same list as its respective past-tense counterpart. This was done to minimize the danger of form priming (Stanners, Neiser, Hernon, & Hall, 1979). Each of the two resulting lists contained 80 existing inflected verbs.

Additionally, we added 20 existing nouns ending on *-de* or *-te* (i.e., identical to the past-tense suffix). As most of these nouns were nominalized adjectives, the words had the structure [adjective] + [de/te], e.g. *groente* ('vegetable', lit. 'green-ty') and *liefde* ('love', lit. 'lovely-ty'). This was done to avoid a bias towards incorrect rejections when a participant notices the seemingly illegal combination of an adjective with a verbal morpheme.

Pseudowords:

The list of "difficult" pseudowords was constructed to emphasize the importance of the decomposition and recombination of constituent morphemes. To this end, five types of pseudowords were created. See Table 2 for an overview.

Table 2: Overview of the different types of difficult pseudowords.

Type	N	Example	Correct form	English equivalent
Irregular simple-past form + past-tense affix	20	*sliepte*	*sliep*	'slept-ed'
Irregularized regulars	20	*spol* (from *spellen* 'to spell', following Dutch irregularity class 3)	*spelde*	'spold' (from 'spell', in association with irregular forms like *tell – told*)
Overregularized irregulars	20	*denkte*	*dacht*	'thinked'
Phoneme-changed nouns ending on *–de*/*–te*	20	*wormte*	*warmte*	'trode' (from *trade*, homophonous with **tray-ed*)
Phonologically illegal regular forms[9]	20	*dansde*	*danste*	---

In the easy condition, 75% pseudowords were phonologically legal nonwords without any apparent morphological complexity, e.g. **blouf*, **stoog*, while 25% were overregularized irregular forms (see Table 2) to avoid a "yes" bias for all forms ending in *-de*/*-te*. 71 of the easy pseudowords were identical with the ones used in Chapter 2. See the Appendix for all included items.

Apparatus

The experiment was programmed using Presentation® (version 14.7, Neurobehavioral Systems, USA). The items were presented in black lower case letters (Arial font size 48) against a white background on a 17-inch iiyama HM703UT monitor. Participants were seated in a sound-attenuated booth.

[9] The choice between the two suffixes *de* and *te* is phonologically predictable from the stem

Procedure

All participants were tested individually and were instructed in person by the experimenter as well as by a standard set of instructions on the computer screen.

The first experimental block was preceded by ten practice trials. Participants were allowed to take short breaks after the practice block as well as between test blocks.

In every trial, first, a fixation cross "+" appeared on the screen for 600 ms, after which the test item appeared for 2000 ms. The experiment was quasi-self-paced; items disappeared after the response. There was no feedback on accuracy.

Results

Two items, *reeg* ('strung') and *morde* ('grumbled'), were excluded from further analyses as they received fewer than 50% correct responses. Further, trials with reaction times longer than 2.5 SDs and shorter than 300 ms were discarded on a per-participant basis, as were trials with incorrect lexical decisions. An average of 34 target items (out of 40, $SD = 3.02$) per participant were included in the analyses. No participants were excluded.

We calculated linear mixed-effects models, using the languageR package (Baayen, 2007) and the lme4 package (Bates, 2005; R Development Core Team, 2011). With backwards elimination, we established the model that best explains reaction times on the basis of the independent within- and between-subjects factors. The fixed factors were centered. Due to the high correlation between lemma frequency and form frequency in our items ($r = .86$), we regressed form frequency from lemma frequency counts and used the residuals as a measure of form frequency. This ensures that form frequency effects reported here are free from potentially confounding influences of lemma frequency.

Table 3: Factors included in the model that best explains reaction times.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.5913	0.0301	218.75	< .001
age	-0.1263	0.0416	-3.03	< .01
pseudoword	0.0689	0.0140	4.91	< .001
lemma frequency	-0.0873	0.0097	-8.98	< .001
form frequency	-0.9523	0.1218	-7.82	< .001
age : pseudoword : form frequency	-0.2241	0.1287	-1.74	< .1
age : pseudoword : regularity : form frequency	0.2875	0.1541	1.87	< .1

Random Factors	Name	Variance explained	Standard Deviation
verb	intercept	0.0018965	0.043549
subject	intercept	0.0182724	0.135175
Residual		0.0400194	0.200048

There were main effects of pseudoword type (easy: 710 ms vs. difficult: 761 ms, $t = 4.91$), age (younger: 693 ms vs. older: 776 ms, $t = -3.03$), lemma frequency ($\beta = -0.087329$, $t = -8.98$) and form frequency ($\beta = -0.952304$, $t = -7.82$), with high frequency leading to shorter reaction times.

There interaction between pseudoword type, form frequency, regularity, and age just failed to reach significance ($t = 1.87$), indicating that pseudoword type might influence younger people in a different way compared to older people. We are aware that splitting the data into subgroups is seen as problematic if the higher-order interaction does not reach significance. However, given that the effect was marginally significant ($p = .062$) and that our hypotheses predicted age differences with regards to the influence of pseudoword type, we decided to investigate the pattern of this trend further. We split the data by age group and analyzed the resulting groups separately. Again, we used linear mixed-effects regression to arrive at the best models explaining the reaction times for younger and older people by backwards elimination.

Table 4: Factors included in the model that best explains onset reaction times of younger people.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.4568	0.03688	175.08	< .001
pseudoword	0.0851	0.03208	2.65	< .01
lemma frequency	-0.7183	0.13831	-5.19	< .001
form frequency	-0.8198	0.15615	-5.25	< .001
lemma frequency : pseudoword	-0.2915	0.16580	-1.76	< .1
form frequency : pseudoword	-0.4539	0.18742	-2.42	< .05
regularity : form frequency : pseudoword	0.2879	0.11383	2.53	< .05

Random Factors		Name	Variance explained	Correlation
verb	intercept	0.001562	0.039522	
subject	intercept	0.028080	0.167572	
	pseudoword	0.018420	0.135722	-0.648
Residual		0.041736	0.204293	

Table 5. Factors included in the model that best explains reaction times of older people.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.5959	0.0321	205.61	< .001
lemma frequency	-0.8649	0.1118	-7.74	< .001
form frequency	-0.9354	0.1137	-8.23	< .001
pseudoword	0.0749	0.0173	4.34	< .001

Random Factors	Name	Variance explained	Standard Deviation	Correlation
verb	intercept	0.00234091	0.048383	
subject	intercept	0.02299130	0.151629	
	lemma frequency	0.00020944	0.014472	-1.00
	pseudoword	0.00514285	0.071714	-0.41 -0.41
Residual		0.03293113	0.181469	

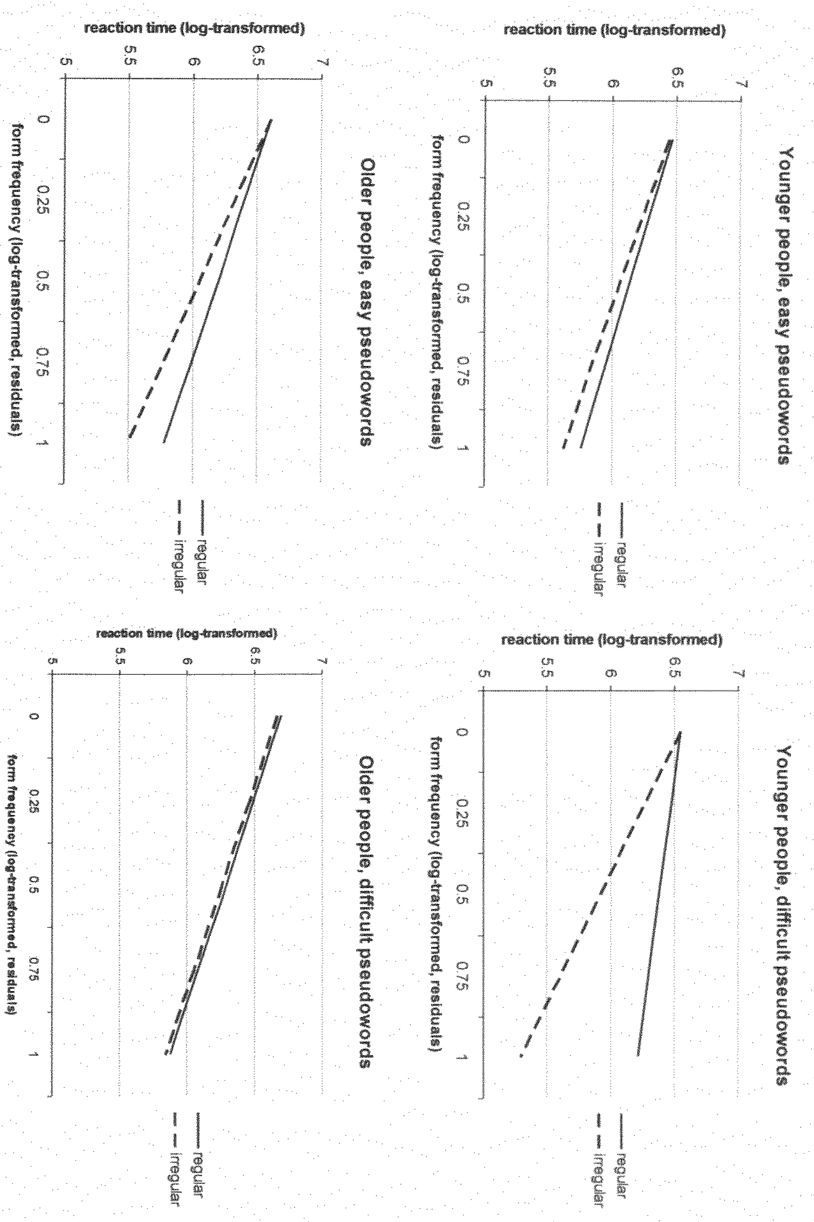


Figure 1: Overview of the reaction times broken down by age group and pseudoword type. Lines are fitted linear regression lines.

For younger people, lemma frequency (t = -5.19), form frequency (t = -5.25), and pseudoword type (t = 2.65) acted as main factors. Reaction times were shorter for high-frequency items and when the pseudowords were easy (easy: 669 ms, difficult: 717 ms). There was a marginally significant interaction between pseudoword type and lemma frequency (t = -1.76) and a significant interaction between pseudoword type and form frequency (t = -5.25). The influence of both lemma frequency and form frequency on reaction times was slightly weaker for easy pseudowords (lemma frequency: t = -4.94; form frequency: t = -5.26) compared to difficult pseudowords (lemma frequency: t = -6.54, form frequency: t = -6.60). Lastly, there was a significant three-way interaction of regularity x form frequency x pseudoword type (t = 2.53). Only in the difficult pseudowords condition, regularity interacted with form frequency (t = 3.32); there was a strong facilitating effect of form frequency for irregular verbs (t = -2.35) but no form frequency effect on regular verbs ($t < 1$). In the easy pseudowords condition, there was no such interaction ($t < 1$).

For older people, there was a main effect of form frequency (t = -8.23) as well as a main effect of lemma frequency (t = -7.74). Further, pseudoword type acted as a main effect (easy: 748 ms, difficult: 805 ms; t = 4.34). There was no interaction between form frequency and regularity in either pseudoword-type condition ($t < 1$).

Discussion of Experiment 1

In this experiment, we investigated the influence of pseudoword material on the processing of regular and irregular past-tense verbs. Our experiment showed that pseudoword material influenced younger people in a different way than older people. In the 'difficult pseudowords' condition, young people displayed the pattern that had been shown previously; they displayed a form frequency effect for irregular items but no such effect for regular items. This frequency-by-regularity interaction is usually taken as evidence for the differential nature of regular vs. irregular processing. Since irregular forms are stored and accessed as fully inflected forms, they are subject to form frequency effects. Regular forms, on the other hand, are computed by attaching an affix onto the stem. This process should not lead to form frequency effects in lexical decisions as the regular forms are accessed only via their lemma. In the easy pseudowords condition, however, young people did not show the frequency-by-regularity interaction that would be indicative of the computation of regular forms.

A potential problem for the interpretation of our results lies in the order in which the two parts of the study were conducted. All participants saw the difficult pseudowords in their first visit and the easy pseudowords during their second visit. This confound could then mean that the real reason behind the effect of pseudoword type is instead whether a person had already participated in the experiment. That is, having recently participated in the first part of the experiment and having encountered the stimuli already may have made the younger participants behave more similar to the older participants. Note, however, that the participants did not see any target item twice. During the second visit, they responded to items from the respective other list, as mentioned in the Method section.

For this reason, we conducted a second lexical-decision experiment, in which a new group of younger and older participants saw only the lists containing the easy pseudowords. If we do not find a difference in how these two groups process regular vs. irregular forms (i.e. no interaction between age, form frequency, and regularity), we can assume that the effect of interest in Experiment 1 is indeed due to the pseudoword type.

Experiment 2

Method

Participants

Each age group consisted of 24 participants (younger people: 19 female, 2 left-handed, $M_{Age} = 21$, $range_{Age} = 18\text{-}27$; older people: 14 female, 3 left-handed, $M_{Age} = 67$, $range_{Age} = 61\text{-}81$).

Of the younger sample, 23 participants were university students or graduates and 1 participant indicated secondary education as his or her highest educational level. Of the older sample, 7 participants were university graduates, 13 had finished technical or vocational training, and 4 indicated secondary education as their highest educational level.

All participants stemmed from the participant pool of the Max Planck Institute for Psycholinguistics, reported having normal or corrected-to-normal vision, and were paid for their participation. All participants provided informed consent to participate in the study and all data were analyzed anonymously.

Materials, Apparatus, Procedure

The stimuli, the apparatus and the procedure were identical to the easy-pseudoword condition in Experiment 1.

Results

Two items, *reeg* ('strung') and *morde* ('grumbled'), were excluded from further analyses so as to ensure comparability with Experiment 1. Further, trials with reaction times longer than 2.5 SDs and shorter than 300 ms were discarded on a per-subject basis as well as trials with incorrect lexical decisions. No participants were excluded. Similar to Experiment 1, an average of 34 target items per participant (out of 40, $SD = 2.65$) were included in the analyses. We performed the same analyses as in Experiment 1.

Table 6: Factors included in the model that best explains reaction times.

Fixed Factors		β	Standard Error	t-value	p
Intercept		6.6330	0.0252	263.74	< .001
lemma frequency		-0.7146	0.1345	-5.31	< .001
form frequency		-0.8158	0.1367	-5.97	< .001
age		-0.1148	0.0342	-3.36	< .001
Random Factors	**Name**	**Variance explained**	**Standard Deviation**	**Correlation**	
verb	intercept	0.0047722	0.069081		
	age	0.0035945	0.059954	-0.313	
subject	intercept	0.0108162	0.104001		
	regularity	0.0019372	0.044014	0.552	
Residual		0.0356177	0.188726		

There was a significant main effect of age ($t = -3.36$), indicating that younger people reacted faster than older people (younger: 695 ms, older: 776 ms), a main effect of lemma frequency ($\beta = -0.71459$, $t = -5.31$), and a main effect of form frequency ($\beta = -0.81576$, $t = -5.97$), with more frequent items leading to faster reactions. There were no significant interactions.

Although age did not interact with any of the factors (age x form frequency x regularity: $t < 1$), we split the data by age group to be able to compare the resulting models with the equivalent data from Experiment 1. Again, we used linear mixed-effects regression to arrive at the best model by backwards elimination.

Table 7: Factors included in the model that best explains onset reaction times of younger people.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.5155	0.0282	231.18	< .001
lemma frequency	-0.8064	0.1694	-4.76	< .001
form frequency	-0.9181	0.1725	-5.32	< .001
Random Factors	**Name**	**Variance explained**	**Standard Deviation**	
verb	intercept	0.005777	0.076007	
subject	intercept	0.016028	0.126601	
Residual		0.036612	0.191343	

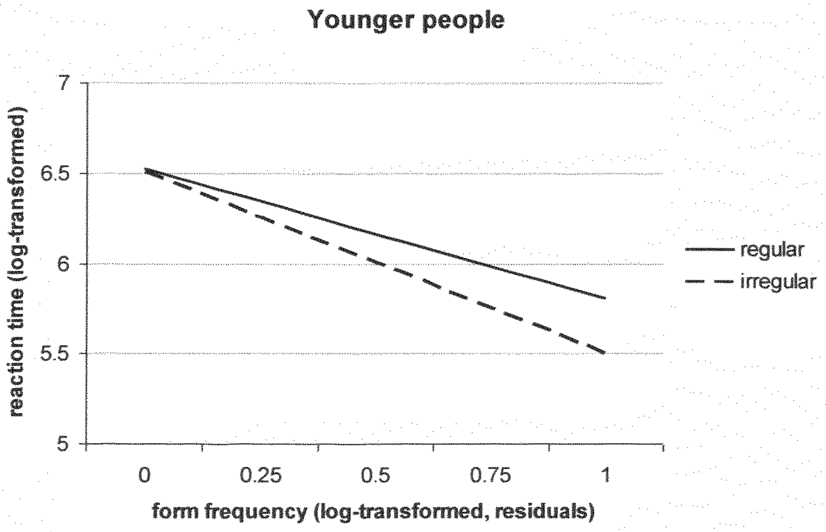


Figure 2: Overview of the reaction times broken down by age group. Lines are fitted linear regression lines.

Table 8: Factors included in the model that best explains reaction times of older people.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.6312	0.0247	268.35	< .001
lemma frequency	-0.6398	0.1534	-4.17	< .001
form frequency	-0.7311	0.1555	-4.70	< .001

Random Factors	Name	Variance explained	Standard Deviation
verb	intercept	0.0046333	0.068068
subject	intercept	0.0121797	0.110362
Residual		0.0357093	0.188969

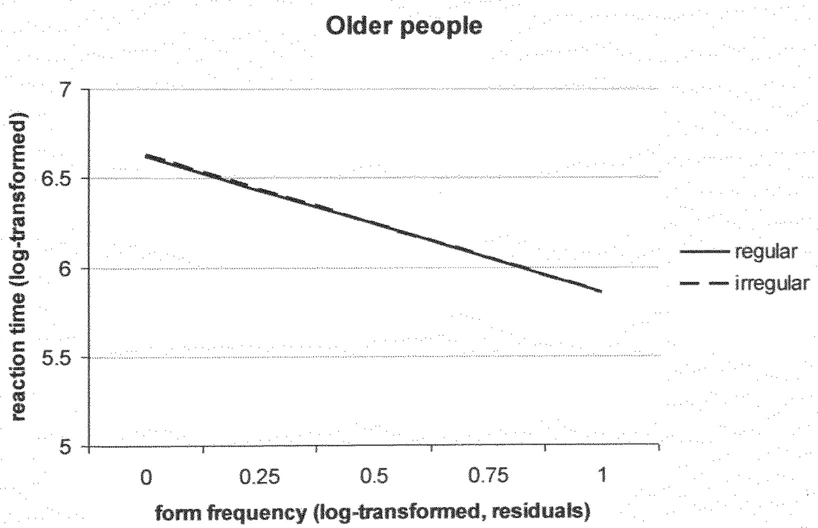


Figure 3: Overview of the reaction times broken down by age group. Lines are fitted linear regression lines.

For younger people, there was a main effect of lemma frequency (β = -0.80642, t = -4.76) and of form frequency (β = -0.91805, t = -5.32), reaction times were shorter for high-frequency items. Similar to the easy-pseudowords condition in Experiment 1, there was no interaction between regularity and form frequency ($t < 1$). For older people, there was a main effect of lemma frequency (β = -0.80642, t = -4.76) and a main effect of form frequency (β = -0.91805, t = -5.32), with more frequent items leading to shorter reaction times. The absence of an interaction between age, form frequency and regularity ($t < 1$) indicates that both age groups behaved in a similar manner with regards to regular vs. irregular items; neither group displayed the interaction between regularity and form frequency found in the difficult-pseudoword condition (both $t < 1$).

There was no significant difference between the reaction times in Experiment 2 compared to Experiment 1 ($t < 1$).

Discussion of Experiment 2

The results from Experiment 2 largely replicate the findings from Experiment 1. When pseudowords are easy, younger and older people display an effect of lemma frequency. Additionally, the overall model showed a main effect of form frequency, which is indicative of whole-word storage. When splitting the data by age, the effect of form frequency just fails to reach significance for the younger people but is significant for the older people. Importantly, neither group showed an interaction between regularity and form frequency, suggesting that in Experiment 2, participants did not decompose morphologically complex words but relied instead on a more storage-based way of processing. It seems that the effect of pseudoword difficulty in Experiment 1 was indeed due to the nature of the pseudowords and not the result of participating in the experiment for the second time.

General discussion

According to the majority of dual-route models of morphological processing, decomposition and whole-word access coexist as two parallel routes. Which of the two routes will eventually be the one that leads to the recognition of a particular form depends on a number of factors.

In the past, many linguistic factors have been established to influence this trade-off between storage and computation (Colé, Beauvillain, & Segui, 1989; Cutler, Hawkins, & Gilligan, 1985; Taft, 1994; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Bybee & Moder, 1983; Pinker & Prince, 1988; Ullman, 1993; Bertram, Laine, & Karvinen, 1999; Bertram et al., 2000). Our previous research indicated that age might have an influence on morphological processing. Numerous studies with children, student samples, and even L2 speakers found an interaction between regularity and form frequency (Bybee & Slobin, 1982; Prasada, Pinker, & Snyder, 1990; Ragnasdóttir, Simonsen, & Plunkett, 1999), suggesting that regular forms are largely computed and irregular forms are accessed as whole words. However, in our previous experiments, older people showed form frequency effects for both regular and irregular past-tense forms, suggesting that older people are generally more prone to using the storage-based route. In the present study, we tried to induce decomposition in older people by highlighting the complex structure of the targets with the help of seemingly morphologically complex pseudoword material. To this end, we manipulated the nature of the pseudowords in a lexical decision experiment to investigate its influence on the depth of processing. Previous work (LaBerge, 1971; James, 1975; Waters & Seidenberg, 1985; Taft, 2004) suggested that "difficult" distractors (i.e., in a lexical decision experiment, pseudowords that are highly similar to the target words) lead to deeper phonological, morphological and semantic processing. In order to judge a stimulus that does not stand out but closely resembles all other stimuli, a deeper level of processing is necessary. Previous work in our lab (as reported in this thesis, Chapter 2) had suggested that older people seem to process morphologically complex words as whole forms instead of decomposing them. Could older people be encouraged to decompose regular past-tense forms if they are presented with difficult pseudowords that seem to be morphologically complex?

We had expected older participants to show a different reaction time pattern depending on whether they saw easy or difficult pseudowords. Difficult pseudowords were thought to lead to a deeper level of morphological processing (i.e., decomposition into constituent morphemes), which is evidenced by a frequency-by-regularity interaction. Easy pseudowords were expected to lead to the same pattern that we had found in the earlier study. As for the younger participants, we did not expect pseudoword type to influence the way they process morphologically complex words (see Table 1). While a main effect would not have been surprising, we expected the same reaction time pattern for easy and difficult pseudowords: an interaction between form frequency and regularity.

Younger people showed different reaction time patterns depending on the nature of the pseudowords. When the pseudowords were difficult, younger people showed an interaction between regularity and form frequency. This interaction has been observed in previous studies (Bybee & Slobin, 1982; Marcus et al., 1995; Prasada, Pinker, & Snyder, 1990; Ullman, 1993; Seidenberg & Bruck, 1990) and is often taken as evidence for dual-route models. Irregular forms are subject to form frequency effects as they are accessed as whole words. Regular items are decomposed into their constituent forms, so they do not display form frequency effects. A different pattern emerged when pseudowords were simple. While younger participants still displayed a main effect of lemma frequency, there was, in contrast to the difficult-pseudoword condition, no interaction between regularity and form frequency. It is conceivable that the ease with which participants could reject an easy pseudoword (reaction times for rejecting an easy pseudoword were 123 ms faster than reaction times for rejections of difficult pseudowords) discouraged them from the time-consuming and cognitively costly decomposition of target items. The nature of the nonwords in the difficult condition, however, highlighted the morphological complexity of the target items. This could then motivate younger participants to decompose all items to ensure accuracy.

However, pseudowords did not influence the reaction time patterns of older people. While their reactions were slower when pseudowords were difficult, there was no obvious difference in the way they processed the morphologically complex target items. Older people displayed main effects of lemma frequency and of form frequency for both regular and irregular forms regardless of the nature of the pseudowords. Such a pattern is an indicator for whole-word processing (Bertram et al., 1999). This replicates our previous findings, which indicate that older people use whole-word access for all forms, as this is the most efficient mechanism in either situation.

Previously, we argued that there might be several reasons for why older people seem to use the storage-based approach. First, higher age might lead to greater accumulated frequency of inflected verb forms due to the life-long exposure to such forms. In line with the observed threshold for storage (Alegre & Gordon, 1999; Lehtonen & Laine, 2003; Soveri, Lehtonen, & Laine, 2007, Lehtonen et al., 2006), storage may then be an effective and fast way to access both regular and irregular forms.

Another reason for the greater reliance on storage may be decreased working memory abilities. Unfortunately, to the best of our knowledge, empirical evidence for the involvement the working memory system in the computation of morphologically complex forms is presently lacking. However, it is conceivable that, as working memory capacities decrease with age (Dobbs & Rule, 1989; Salthouse, 1991; Salthouse

& Babcock, 1991), computational processes become slower, rendering whole-word access a more efficient strategy.

In conclusion, the present study replicates our previous findings suggesting that young people can make use decomposition as an accurate and fast way to process morphologically complex words. Older people, on the other hand, rely on a more storage-based strategy, which may be rooted in their lifelong experience with inflected forms or a decrease in computational capacities.

We demonstrated that the nature of distractor material (in this case: pseudowords) might influence the depth of processing. More difficult pseudowords led to deeper morphological processing in younger people only. Taken together, there does not seem to be a single way of processing all words for all people under all circumstances. Instead, we find support for parallel dual-route systems. Our language processing system is able to adapt to the situation at hand and changes over the course of life.

Appendix

Table A1: List of target items by regularity, incl. gloss and log-transformed lemma and form frequency of the past-tense form.

		Frequency			Average RT (in ms)*		Average accuracy*	
Infinitive	Item	Lemma	Form	Gloss	Easy	Difficult	Easy	Difficult
regular								
beven	beefde	7.23	5.80	to tremble	778	805	1.00	0.91
blozen	bloosde	6.53	5.63	to blush	712	798	0.91	0.87
dulden	duldde	6.46	4.73	to endure	787	819	0.86	0.62
glippen	glipte	6.03	5.21	to slip	764	798	0.95	0.83
gloeien	gloeide	6.91	5.29	to glow	720	733	0.96	1.00
gooien	gooide	8.43	7.38	to fling	648	722	0.96	1.00
hijgen	hijgde	7.31	6.04	to pant	805	729	0.83	0.96
hink	hinkte	5.55	4.34	to limp	813	753	0.84	1.00
huilen	huilde	8.43	5.12	to howl	620	717	1.00	0.96
kauwen	kauwde	6.54	5.12	to chew	797	745	0.82	0.95
kennen	kende	9.98	8.44	to know	676	706	0.96	1.00
leven	leefde	9.30	7.70	to live	720	704	0.95	0.90
leiden	leidde	7.64	7.10	to lead	704	793	0.92	0.80
leunen	leunde	10.19	7.53	to lean	671	725	1.00	0.92
maken	maakte	11.37	9.58	to make	652	705	0.83	0.88
melden	meldde	7.49	6.16	to report	668	790	0.90	0.83
mengen	mengde	7.07	5.06	to mix	666	766	1.00	0.86
morren‡	morde	5.43	3.14	to grumble	---	---	0.36	0.29
naaien	naaide	6.12	3.97	to sew	644	742	1.00	0.89
richten	richtte	9.02	7.48	to aim	663	753	1.00	0.88
rillen	rilde	6.43	5.55	to shiver	687	778	1.00	0.96
roeien	roeide	6.29	4.37	to row	788	798	0.96	1.00
schudden	schudde	8.56	8.18	to shake	727	708	0.96	1.00
spelen	speelde	9.69	7.91	to play	609	730	0.96	1.00
spreiden	spreidde	7.15	6.08	to spread	680	766	0.96	1.00
storen	stoorde	7.24	5.11	to disturb	676	897	1.00	0.95
strelen	streelde	7.58	6.88	to stroke	788	705	1.00	1.00
trachten	trachtte	8.41	7.00	to attempt	814	856	1.00	0.71
turen	tuurde	6.68	5.95	to peer	763	771	0.96	0.96
villen	vilde	4.73	1.79	to skin	849	994	0.64	0.57
voelen	voelde	10.28	9.54	to feel	611	709	1.00	0.96
volgen	volgde	9.99	7.97	to follow	626	789	0.95	0.86
vullen	vulde	8.08	6.72	to fill	633	798	0.95	0.88
waken	waakte	6.57	4.41	to wake	752	728	0.91	0.95
weven	weefde	8.06	6.29	to weave	724	896	0.85	0.67
wekken	wekte	7.87	7.24	to take	801	724	0.92	0.91
wenden	wendde	5.58	2.56	to turn	781	840	0.91	0.80
wonen	woonde	9.11	7.70	to reside	634	706	0.96	0.95
zwaaien	zwaaide	7.76	6.89	to wield	692	762	0.91	1.00
zwenken	zwenkte	5.18	4.69	to turn	756	824	0.87	0.96
irregular								
blijven	bleef	10.87	9.63	to stay	660	687	1.00	0.88
blinken	blonk	6.50	4.90	to shine	768	807	0.83	0.70
brengen	bracht	10.51	8.86	to bring	703	648	0.95	0.96
drijven	dreef	9.39	8.31	to float	688	657	0.96	0.95

* Only for Experiment 1.

‡ Excluded due to low accuracy.

Infinitive	Item	Frequency Lemma	Form	Gloss	Average RT (in ms)* Easy	Difficult	Average accuracy* Easy	Difficult
dragen	droeg	8.12	6.79	to carry	661	674	1.00	0.96
drinken	dronk	8.82	7.42	to drink	604	729	0.92	1.00
druipen	droop	6.56	5.56	to drip	837	883	0.75	0.96
glijden	gleed	8.07	7.14	to slide	717	823	0.96	0.88
glimmen	glom	7.02	5.21	to glimmer	736	868	0.91	0.65
grijpen	greep	8.33	7.24	to grasp	668	710	1.00	0.96
heffen	hief	7.73	7.00	to lift	705	776	0.57	0.91
houden	hield	9.37	7.33	to help	608	666	1.00	1.00
helpen	hielp	10.75	9.48	to hold	594	645	1.00	1.00
klinken	klonk	9.00	8.35	to sound	696	752	1.00	0.92
kruipen	kroop	7.95	6.93	to crawl	649	759	1.00	0.88
liegen	loog	7.35	5.63	to lie	694	873	0.90	0.88
mijden	meed	5.61	3.81	to avoid	877	862	0.72	0.90
nemen	nam	10.69	9.40	to take	651	666	0.96	1.00
rijgen†	reeg	4.91	2.64	to string	---	---	0.52	0.49
schelden	schold	6.49	5.15	to scold	751	695	0.92	0.96
schenden	schond	5.42	2.71	to violate	866	761	0.65	0.70
schrijden	schreed	5.40	4.68	to stride	828	827	0.68	0.78
smijten	smeet	6.85	5.99	to hurl	711	825	0.91	0.83
spreken	sprak	10.13	8.71	to speak	636	614	1.00	1.00
stinken	stonk	6.97	5.64	to stink	700	690	0.88	0.96
stuiven	stoof	6.00	1.39	to dash	701	936	1.00	0.87
treffen	trof	8.25	6.86	to meet	649	739	0.96	0.87
vreten	vrat	6.32	4.52	to eat	819	882	0.50	0.74
vriezen	vroor	6.18	4.51	to freeze	878	748	0.83	0.82
werpen	wierp	7.19	5.77	to throw	707	677	0.96	1.00
winnen	won	8.49	7.72	to win	676	650	0.92	0.95
wegen	woog	8.13	6.24	to weigh	702	709	0.88	0.76
wrijven	wreef	7.61	6.91	to rub	685	838	1.00	0.88
zenden	zond	7.47	6.12	to send	770	975	0.73	0.65
zingen	zong	8.35	6.74	to sing	686	677	0.96	1.00
zuigen	zoog	7.18	5.98	to suck	698	843	0.96	0.92
zuipen	zoop	5.47	3.56	to drink	781	806	0.84	0.77
zwerven	zwierf	6.51	4.91	to wander	727	917	0.91	0.82
zwellen	zwol	7.36	5.48	to swell	730	696	0.83	0.83
zwemmen	zwom	6.54	5.04	to swim	691	730	0.96	0.86

B1: List of easy pseudowords and (if applicable) their corresponding existing form.

Overregularized irregulars

Item	Existing form	Item	Existing form	Item	Existing form
bergde	borg	kiesde	koos	spijtte	speet
blijkte	bleek	komde	kwam	strijdde	streed
blinkte	blonk	leesde	las	strijkte	streek
breekte	brak	rijdde	reed	trekte	trok
graafde	groef	roepte	riep	valde	viel
hangde	hing	schijnde	scheen	vliegde	vloog
knijpte	kneep	slaapte	sliep	windde	wond
krijgde	kreeg	sluipte	sloop	zinkte	zonk

Other pseudowords

bloof	hoel	ploun	schreem	wocht
blouf	kliet	pous	schroon	woeg
brong	klocht	praas	smalt	woek
boof	kloop	proet	smok	woen
deek	kriet	prool	splots	wonk
dees	loed	reek	spreed	wroot
dricht	loen	reem	stoch	wuid
dweng	lout	riest	stoog	zerg

eel	malk	rocht	storf	zief
fliep	mod	roed	trif	zoerg
foots	moen	roop	troed	zwal
frouk	niek	rouk	vicht	zwarm
geet	niem	schief	vong	
gonk	pach	sching	vorf	
goof	plerk	schoet	vroos	
haf	plits	schord	wien	

B2: List of difficult pseudowords and their corresponding existing form.

Item	Existing form (infinitive)	Item	Existing form (infinitive)
overregularized irregulars			
bergde	borg (bergen)	lijkte	leek (lijken)
blaasde	blies (blazen)	melkte	molk (melken)
breekte	brak (breken)	slijpte	sleep (slijpen)
buigde	boog (buigen)	sluipte	sloop (sluipen)
denkte	dacht (denken)	snuifde	snoof (snuiven)
duikte	dook (duiken)	springde	sprong (springen)
dwingde	dwong (dwingen)	strijkte	streek (strijken)
graafde	groef (graven)	werfde	wierf (werven)
kiesde	koos (kiezen)	wijsde	wees (wijzen)
koopte	kocht (kopen)	zwijgde	zweeg (zwijgen)
irregularized regulars			
broon	bruinde (bruinen)	peens	peinsde (peinsen)
dweel	dweilde (dweilen)	proom	pruimde (pruimen)
eel	ijlde (ijlen)	reem	rijmde (rijmen)
eek	ijkte (ijken)	rool	ruilde (ruilen)
groon	griende (grienen)	soor	sierde (sieren)
jooch	juichde (juichen)	spol	spelde (spellen)
knool	knuilde (knuilen)	toot	tuitte (tuiten)
krood	kruidde (kruiden)	veens	veinsde (veinsen)
kweel	kwijlde (kwijlen)	zeel	zeilde (zeilen)
loed	laadde (laden)	zwoop	zwiepte (zwiepen)
phonologically illegal regulars			
bakde	bakte (bakken)	spaarte	spaarte (sparen)
dansde	danste (dansen)	stapde	stapte (stappen)
diente	diende (dienen)	tikde	tikte (tikken)
durfte	durven (durfde)	visde	viste (vissen)
lachde	lachte (lachen)	voerte	voerde (voeren)
noemte	noemde (noemen)	vormte	vormde (vormen)
poetsde	poetste (poetsen)	wasde	waste (wassen)
reiste	reizen (reisde)	wenkde	wenkte (wenken)
roerte	roerde (roeren)	werkde	werkte (werken)
schilte	schilde (schillen)	zorgte	zorgde (zorgen)
irregular SP forms with affixes			
drongde	drong (dringen)	sloegde	sloeg (slagen)
hingde	hing (hangen)	slonkte	slonk (slinken)
keekte	keek (kijken)	speette	speet (spijten)
klomde	klom (klimmen)	steegde	steeg (stijgen)
kneepte	kneep (knijpen)	trokte	trok (trekken)
krompte	kromp (krimpen)	vielde	viel (vallen)
liepte	liep (lopen)	vingde	ving (vangen)
riepte	riep (roepen)	vloogde	vloog (vliegen)
schoorde	schoor (scheren)	vroegde	vroeg (vragen)
sliepte	sliep (slapen)	zonkte	zonk (zinken)

Processing of Dutch noun plurals in younger and older speakers

Chapter 4

Abstract

In previous studies, we found evidence that younger people decompose regular inflected past-tense forms while older people access them as whole words. The present experiment investigates whether these findings can be generalized to nouns by comparing singular-dominant and plural-dominant nouns and the influence of form frequency. Different models of morphological processing predict different reaction time patterns, based on their assumptions on what is stored in the mental lexicon.
We tested 25 younger and 25 older Dutch native speakers in a lexical decision task, with target words taken from Baayen, Dijkstra, and Schreuder (1997).
The results revealed three interesting points. First, and replicating the pattern found by Baayen, Dijkstra et al. (1997), an interaction between the number and the number dominance of a given word: there was an effect of presented number for singular-dominant words (higher reaction times for plural form than for singular form), but not for plural-dominant words (similar reaction times for singular und plural forms). This suggests that low-frequency plurals are parsed and high-frequency plurals are accessed from the mental lexicon as full forms.
A second analysis using form frequency as a continuous factor showed interaction between form frequency, number, and dominance: only plural-dominant plural forms showed a form-frequency effect, suggesting that only these forms are stored.
Lastly, there were no differences in the reaction time pattern between younger and older people. Older people seem to decompose noun plurals. We discuss differences in frequency, concreteness, and morphological complexity between the nouns and verbs as possible origins of the differences in the findings seen for nouns and verbs.

One of the main debates in the field of morphology concerns the representation of morphologically complex words in the mental lexicon. With respect to inflection, single- vs. dual-route models disagree about whether regularity influences the way in which inflected words are processed. Single-route accounts propose that regular inflections (e.g., *pointed*) and irregular ones (e.g. *wept*) follow a similar pathway. But the single routes proposed differ as to whether complex words are stored or computed. Proponents of full-listing (Butterworth, 1983) claim that all inflected forms, regular and irregular ones, are stored, pointing to the cognitive costs associated with on-line computation of inflections. Advocates of full decomposition (e.g. Taft, 1979, 2004; Taft & Forster, 1975) propose that all morphologically complex forms are obligatorily decomposed into their constituent morphemes and that there are no stored representations of complex forms.

Dual-route models, on the other hand, handle regular and irregular morphology differently. While regular forms are processed by decomposition into their constituent morphemes, irregular forms are stored in the mental lexicon and connected to their lemmas via associative links. Models differ in how strictly, if at all, these routes are assumed to be separate from each other. Schreuder and Baayen (1995) proposed a parallel dual-route race model in which the computational and the storage-based route compete with each other in one system. Other models claim the existence of two largely independent systems (e.g. Lexicon & Grammar in Pinker & Ullman, 2002; procedural vs. declarative system in Ullman, Bergida, & O'Craven, 1997).

The augmented addressed morphology (AAM) model (Burani & Caramazza, 1987; Caramazza, Laudanna, & Romani, 1988; Laudanna & Burani, 1985) postulates that "known" words are accessed from storage and only novel or rare forms are decomposed. Milder versions of this view claim that high-frequency regular forms are stored and low-frequency regulars are computed (Burani & Laudanna, 1995; Chialant & Caramazza, 1995; Laudanna & Burani, 1992; Alegre & Gordon, 1999).

Previous research has shown that, besides frequency, a number of other linguistic factors influence whether morphologically complex words are accessed from storage or via decomposition. Among those factors are affix type (Colé, Beauvillain, & Segui, 1989; Cutler, Hawkins, & Gilligan, 1985; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Taft, 1994), semantic transparency (Marslen-Wilson et al., 1994; Feldman & Soltano, 1999, but see Roelofs & Baayen, 2002; Lüttmann et al., 2011; Andrews & Lo, 2013) as well as affixal productivity and homonymy (Bertram, Laine, & Karvinen, 1999; Bertram, Schreuder, & Baayen, 2000).

In the previous experiments (Chapters 2 and 3), we found evidence that besides the linguistic material, cognitive factors play a role in the processing of morphologically complex words. Three lexical-decision experiments yielded strong main effects of, and interactions with, the age of our participants. Replicating a number of studies (Bybee & Slobin, 1982; Prasada, Pinker, & Snyder, 1990, Ullman, 1993; but see Daugherty & Seidenberg, 1992, 1994; Tabal, Schreuder, & Baayen, 2010; Woollams, Joanisse, & Patterson, 2009), younger participants showed an interaction between regularity and form frequency, indicating that they decomposed regular inflected words but accessed irregular forms via direct storage. This finding is in line with predictions made by dual-route models; as memory traces get stronger with additional exposure, irregular forms stored in the lexicon will be subject to frequency effects. This is not the case for regular forms, which are computed on-line. In our experiments, older participants showed a different pattern of results. They did not seem to distinguish between regular and irregular verbs but exhibited form-frequency effects for all forms, suggesting that they accessed even decomposable regular forms via a storage-based route. Chapter 3 showed the stability of this greater reliance on storage by older participants, even when the decompositional nature of the regular forms was highlighted through nonword distractors such as *sliepte* (irregular past tense of *slapen* + regular past tense affix *–te*, English equivalent: *slepted*). The present chapter addresses the question whether these age differences in morphological processing are generalizable and also hold for noun inflections. We will use two ways of analyzing reactions to singular and plural noun forms. Analysis I follows the analysis by Baayen, Dijkstra, & Schreuder (1997), focusing on effects of number and number dominance and comparing our findings to their findings. Analysis II includes form frequency as a continuous predictor of reaction times for items stored in the mental lexicon.

Number dominance in nouns

Number dominance is the (im-)balance between the form frequencies of the singular and the plural form of a word. Across the entire lexicon, singular forms are somewhat more frequent than plural forms (Baayen, Levelt, Schreuder, & Ernestus, 2008); however, there are numerous examples of so-called plural-dominant words, denoting objects that typically occur in pairs or groups. For instance, while the form frequency of *bride* is higher than the form frequency of *brides* (181 vs. 29, as measured in CELEX, Baayen, Piepenbrock, & Gulikers, 1995), the form frequency of *pea* is lower than the form frequency of *peas* (30 vs. 145).

Different models of morphological processing predict different reaction time patterns, outlined in Figure 1.

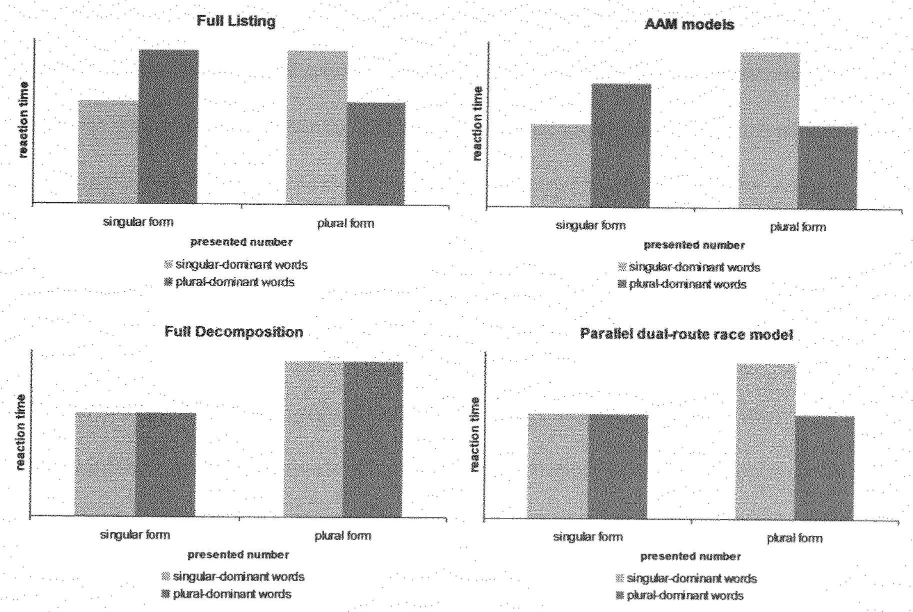


Figure 1: Reaction-time patterns predicted by four different models of morphological processing. (Adapted from Baayen, Dijkstra et al., 1997).

Under a full-listing account, all inflected forms are stored. This results in facilitation whenever a noun is presented in its dominant (i.e. more frequent) number; *peas* will lead to faster reactions than *pea*, *bride* will lead to faster reactions than *brides*. (See upper left panel of Figure 1)

AAM models assume that most known forms are accessed via storage and thus predict an interaction similar to the Full-Listing model. However, as mentioned above, some versions of these models consider decomposition for low-frequency words, so a singular-dominant plural form like *brides* might require some processing time; this leads to slightly longer reaction times compared to its equally low-frequency, but monomorphemic counterpart *pea*, resulting in a more asymmetrical pattern compared to the Full-Listing model (See upper right panel of Figure 1).

Full Decomposition, on the other hand, assumes that all morphologically complex forms are parsed. This means, that only lemma frequencies[10] will influence reaction times (Bertram et al., 2000). When these are held constant for singular- and plural-dominant nouns, reactions to singular- and plural-dominant nouns should be equally fast. Assuming that the parsing of a complex form takes time, a full decompositional view predicts longer reaction times for *peas* and *brides* than for *pea* and *bride* (See lower left panel of Figure 1).

Dual-route race models (e.g. Schreuder & Baayen, 1995) predict that the speed of recognizing a *singular* form is determined by the summed frequency of the singular and plural form. The recognition time for a plural form, however, is determined by its plural form frequency. The underlying logic goes as follows. Both singular and plural forms of a word are stored in the mental lexicon. Whenever a transparent plural form is encountered, this will lead to a boost in activation for the corresponding singular form (because it is contained in the input) as well as for the plural form. This relationship is asymmetric. Encountering a singular form will not lead to a boost in activation for its plural representation because the plural form is not contained in the visual signal. When a plural form is to be recognized, two parallel processes start. One decompositional process parses the word into its morphemes and looks up the stem. At the same time, a storage-based process searches for the entire form in the lexicon. Whichever process is faster is the one to output the result. For singular-

[10] In CELEX (Baayen, Piepenbrock, & Gulikers, 1995), lemma frequencies are the sum of the form frequencies of all inflections of a word of the same word class. That is, the lemma frequency for *loop* ('run', noun) is the added frequency of *loop* (singular form) and *lopen* (plural form). Note that its lemma frequency does not include the form frequency for the verb forms *loop* (singular present tense) or *lopen* (plural present tense).

dominant forms, this leads to an effect of number; their singular forms (*bride*) are easy to recognize but their plural forms (*brides*) need first to be decomposed which costs time. Plural-dominant words, however, should not exhibit an effect of number; their singular forms (*pea*) profit from the high frequency of their plural forms and are recognized fast, their plural forms are highly frequent and are recognized fast via the storage route (*peas*). (See lower right panel of Figure 1.)

Baayen, Dijkstra et al. (1997, visual presentation) and Baayen, McQueen, Dijkstra, & Schreuder (2003, auditory presentation) examined the effects of dominance (singular-dominant vs. plural-dominant), number (singular form vs. plural form), and lexeme frequency (low vs. high) on reaction times in a lexical decision experiment. In both studies, the authors found an interaction of dominance by number. There was an effect of number for singular-dominant nouns (*brides* yielded longer reaction times than *bride*) but no such effect for plural-dominant nouns (reactions to *pea* were as fast as reactions to *peas*). See Figure 2.

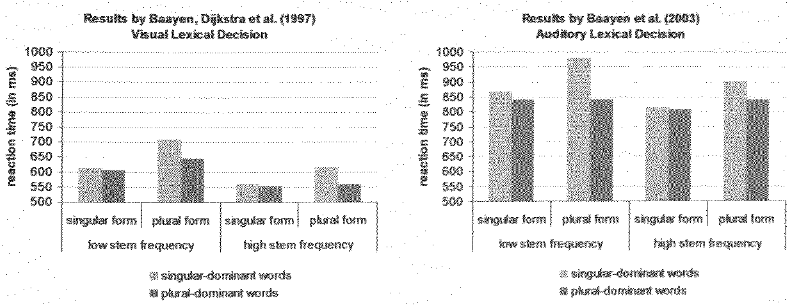


Figure 2: Results obtained by Baayen, Dijkstra et al. (1997) and Baayen et al. (2003). Both experiments found an interaction between Number and Dominance.

This pattern is in line with the predictions from the parallel dual-route model race proposed by Schreuder and Baayen (1995), see Figure 1, lower right panel.

Reaction times for singular forms are a function of summed singular-form frequencies and plural-form frequencies, leading to similar reaction times for singular-dominant and plural-dominant words. Reaction times to plural forms depend on the plural form frequency; singular-dominant plural forms are accessed via the decomposition route, while plural-dominant plural forms are accessed via the storage route, leading to faster reactions to plural-dominant words compared to singular-dominant words.

Similar reaction time patterns were observed for French (New, Brysbaert, Segui, Ferrand, & Rastle, 2004), Spanish (Dominguez, Cuetos, & Segui, 1999) and Italian (Baayen, Burani, & Schreuder, 1997). Studies on English nouns seemed to contradict the predictions made by dual-route models at first glance: Sereno and Jongman (1997) as well as New et al. (2004) found longer reaction times for singular forms of plural-dominant nouns (e.g. *pea*) compared to singular forms of singular-dominant nouns (e.g. *bride*), a pattern that seems to confirm a full-listing approach; however, Baayen et al. (2008) argue that this might be due the use of lexeme frequency as a dichotomous (rather than a continuous) factor.

Frequency and the storage/decomposition trade-off

In addition to the original analysis used by Baayen, Dijkstra et al. (1997), we will investigate the effects of form frequency as in Chapters 2 and 3. Form frequency is a common diagnostic of storage. If a form is stored in the mental lexicon (rather than decomposed), we expect effects of both form frequency and lemma frequency. If form frequency does not influence reaction times, this indicates that the form in question is not stored but decomposed instead (Bertram et al., 2000). Compared to Analysis 1, this analysis makes use of the continuous nature of form frequency as a predictor.

The different models of morphological processing predict different reaction-time patterns with regard to form frequency. Full-listing models assume that all inflected forms are stored; they expect all transparent plural forms to display form-frequency effects. Full decomposition models, on the other hand, claim that all transparent morphologically complex forms are decomposed into their constituent morphemes, so reactions to plural forms should not be influenced by form frequency.

Dual-route models, such as the parallel dual-route race model (Schreuder & Baayen, 1997) predict different patterns for the plural forms of singular-dominant compared to plural-dominant nouns. Singular-dominant words have relatively low frequency plurals, so the decomposition route is likely to win in the race between the two competing route, leading to no form-frequency effect. Plural-dominant words, however, have highly frequent plurals which are usually accessed faster by the storage route, leading to a form frequency effect for these forms.

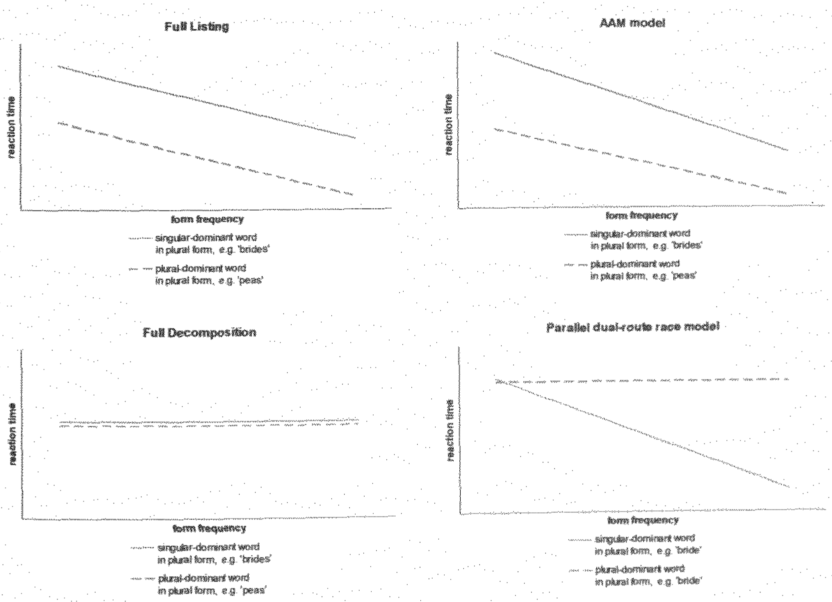
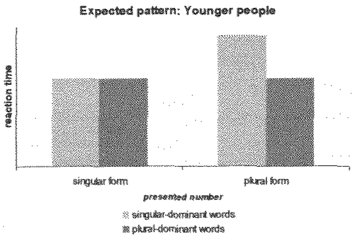
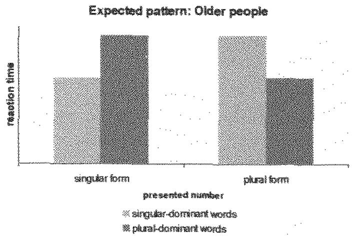
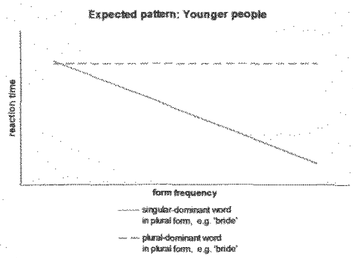
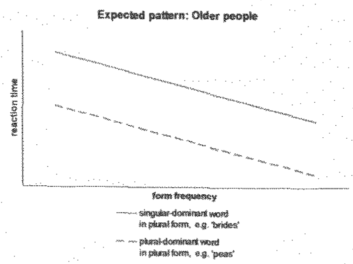


Figure 3: Assumptions made by different models with regards to form frequency

Research on morphological decomposition of nouns has so far only been done with young participants. As mentioned earlier, our previous work indicated that older people use whole-word access to process past-tense forms of verbs, while younger people decompose these forms. If these findings for verbal inflections can be generalized to nouns, one would expect a different pattern for younger and older people. While young people are expected to exhibit the same pattern as in the experiment by Baayen, Dijkstra et al., 1997, older people might show a pattern that is more in line with the predictions made by full-listing accounts, as illustrated in Table 1. For this reason, we decided to conduct an experiment similar to the one by Baayen, Dijkstra, et al., 1997) including an older sample.

Table 1: Predicted reaction time patterns by the two analyses described above. Young people are expected to show a pattern similar to the one found by Baayen and colleagues. If our findings for verbs from Chapters 2 and 3 generalize to nouns, we expect older people to show an effect of Dominance for singular forms and an effect of form frequency for all words in their plural form.

<table>
<tr><th></th><th>Younger people</th><th>Older people</th></tr>
<tr><td>Analysis I: Number x Dominance</td><td>
</td><td>
</td></tr>
<tr><td>Analysis II: Form Frequency</td><td>
</td><td>
</td></tr>
</table>

The design included form frequency (continuous), lemma frequency (continuous), presented number (singular vs. plural), and dominance (singular-dominant vs. plural-dominant) as within-subjects factors, and age (young vs. old) as between-subjects factor.

Method

Participants

The younger age group consisted of 25 participants (20 female, 4 left-handed, $M_{Age} = 21$, $range_{Age} = 18\text{-}23$). The older age group likewise consisted of 25 participants (15 female, 1 left-handed, $M_{Age} = 68$, $range_{Age} = 60\text{-}75$). 48 of these participants had previously participated in the first experiment described in Chapter 3. All participants stemmed from the participant pool of the Max Planck Institute for Psycholinguistics, reported having normal or corrected-to-normal vision, and were paid for their participation. All participants provided informed consent to participate in the study and all data were analyzed anonymously.

Materials

The set of stimuli consisted of 432 existing Dutch words and 432 pseudowords, the latter were created by changing one phoneme of an existing word (usually a vowel).

The target items were identical to the ones used by Baayen, Dijkstra et al. (1997). 93 singular nouns and their corresponding 93 plural forms were split into two groups according to whether they were singular- or plural-dominant. The items were matched for lemma frequency (singular-dominant: 6.61, plural-dominant: 6.48).

bigram frequency (as reported in CELEX, Baayen, Piepenbrock, & Gulikers, 1995), and length.

For all target items, the plural is formed by adding the suffix *–en* onto the singular form[11]. See Table 2 for an overview of the stimulus categories and Table A1 in the Appendix for the full list of stimuli.

Table 2: Overview of the stimuli categories.

Type		Form Frequency Singular	Plural	N	Total
Target items					
	Singular-dominant	6.49	4.72	46	
	Plural-dominant	5.36	6.14	47	
					93 x 2
Filler items	Adjectives, adverbs, s-plural nouns				123
Pseudowords	Phoneme-changed versions of the target, and filler items				216
Total					432

The stimulus material was divided over two lists of 432 items each, so that participants saw only one form per item, either its singular or its plural form. Half of the participants saw list a, the other half saw list b.

[11] Dutch has two plural affixes, *-en*, and *–s*; which of the two is used is largely predictable from phonology (Baayen, Schreuder, de Jong, & Krott, 2002; van Wijk, 2002; Keuleers et al., 2007). Additionally, *-eren* which is used for a very small number of neuter nouns (see Booij, 2002, for a discussion on its status as a suffix).

Apparatus

The experiment was programmed using Presentation® (version 14.7, Neurobehavioral Systems, USA). The items were presented in black lower case letters (Arial font size 48) against a white background on a 17-inch iiyama HM703UT monitor. Participants were seated in a sound-attenuated booth.

Procedure

All participants were tested individually and were instructed by the experimenter as well as by a standard set of instructions on the computer screen.

There were four experimental blocks with 108 items each. The first experimental block was preceded by 10 practice trials. Participants were allowed to take short breaks after the practice block as well as between the four test blocks.

On every trial, first, a fixation cross "+" appeared on the screen for 600 ms, after which the test item appeared for 2600 ms. The experiment was quasi-self-paced; items disappeared after the first response. There was no feedback on accuracy.

Results

Four items (*boegen* 'bows' (front of a ship), *loepen* 'lenses', *ponten* 'ferries', *stouten* 'stouts') received fewer than 50% correct reactions, so both the singular and the plural form were excluded from further analyses. Further, trials with reaction times more than 2.5 SDs above the mean and shorter than 300 ms were discarded on a per-subject basis, as were trials with incorrect lexical decisions. No participants were excluded.

Analysis 1: Effects of Number x Dominance

We performed Linear Mixed Effects Models, using the languageR package (Baayen, 2007) and the lme4 package (Bates, 2005; R Development Core Team, 2011). With backwards elimination, we established the model that best explained reaction times on the basis of the independent factors of the items (Dominance, Lemma Frequency, Presented Number) and the subjects (Age). The fixed factors were centered.

Table 3: Factors included in the model that best explains reaction times.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.5831	0.0429	153.37	< .001
lemma frequency	-0.0191	0.0042	-4.52	< .001
dominance	0.0537	0.0128	4.21	< .001
lemma frequency : age	-0.0181	0.0049	-3.65	< .001
number : dominance	-0.0552	0.0099	-5.59	< .001

Random Factors	Name	Variance explained	Standard Deviation	Correlation
noun	intercept	0.0022158	0.0470719	
	age	0.0019686	0.0443691	0.04
subject	intercept	0.0342520	0.1850726	
	lemma frequency	0.0000849	0.0092156	-0.69
	number	0.0009824	0.0313433	-0.79 0.68
Residual		0.0238830	0.1545405	

There was a main effect of lemma frequency, with more frequent words leading to faster reactions ($\beta = -0.019091$, $t = -4.52$). Lemma frequency, in turn, interacted with age ($t = -3.65$); the effect of lemma frequency was larger for younger people ($\beta = -0.036455$, $t = -6.99$) compared to older people ($\beta = -0.018696$, $t = -4.8$).

Lastly, number interacted with dominance; follow-up analyses revealed that number dominance had an effect on reactions to plural forms (singular-dominant: 653 ms, plural-dominant: 616 ms, $t = 3.01$), but not on reactions to singular forms ($t < 1$). There was no interaction between age, number, and dominance ($t = -1.02$), indicating that there was no difference in reaction time pattern between the two age groups.

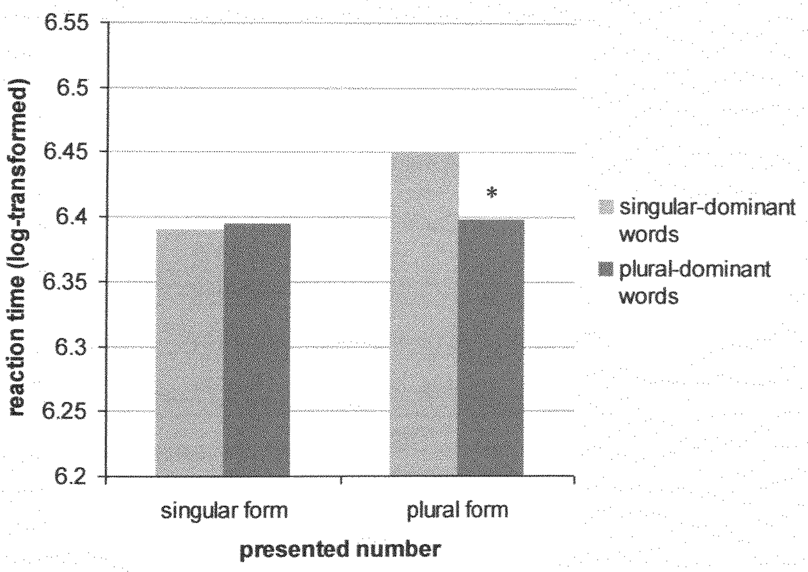


Figure 4: Reaction times of both younger and older people broken down by presented number and dominance.

Analysis II: Effects of form frequency:

We performed linear mixed-effects models, using the languageR package (Baayen, 2007) and the lme4 package (Bates, 2005; R Development Core Team, 2011). With backwards elimination, we established the model that best explained reaction times on the basis of the independent factors of the items (Form Frequency, Lemma Frequency, Number) and the subjects (Age). The fixed factors were centered.

To avoid effects of collinearity between lemma frequency and form frequency ($r = .58$), we regressed form frequency from lemma frequency counts and used the residuals as a measure of form frequency. This ensures that form frequency effects reported here are free from potentially confounding influences of lemma frequency.

Table 2: Factors included in the model that best explains reaction times.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.4350	0.0304	211.99	< .001
age	-0.1539	0.0352	-4.37	< .001
lemma frequency	-0.0514	0.0192	-2.69	< .01
dominance	0.0564	0.0196	2.88	< .01
number	0.0266	0.0131	2.04	< .05
lemma frequency : age	-0.01576	0.0049	-3.24	< .01
form frequency : dominance	0.0721	0.0215	3.35	< .001
dominance : number	-0.0717	0.0204	-3.51	< .001
form frequency : dominance : number	-0.0624	0.0279	-2.24	< .05

Random Factors	Name	Variance explained	Standard Deviation	Correlation		
Noun	intercept	0.00418371	0.0646816			
	number	0.00070956	0.0266376	-0.33		
	form frequency	0.00004816	0.0069397	0.48	0.67	
Subject	intercept	0.04156401	0.2038725			
	lemma frequency	0.00021269	0.0145839	-0.75		
	number	0.00103492	0.0321702	-0.72	0.50	
	dominance	0.00020073	0.0141679	0.81	-0.78	-0.93
Residual		0.02412194	0.1553124			

There was a main effect of lemma frequency, with more frequent words leading to faster reactions ($\beta = -0.05144$, $t = -4.37$), as well as a main effect of age, with younger participants (586 ms) reacting faster than older participants (659 ms),

t = -4.37. Lemma frequency, in turn, interacted with age (t = -3.24); the effect of lemma frequency was larger for young people (β = -0.04128, t = -5.45) compared to older people (β = -0.019299, t = -2.48).

Further, there was a main effect of dominance (t = 2.88), reactions to singular-dominant forms (613 ms) were significantly slower than reactions to plural-dominant words (616 ms). A main effect of number (t = 2.04) showed that reactions to singular forms (613 ms) were significantly faster than reactions to plural forms (636 ms).

Dominance and number interacted with each other; the effect of dominance was in fact only present for plural forms (t = 3.01) but not for singular forms (t < 1). Further, there was an interaction between form frequency and dominance. Follow-up analyses revealed that form frequency had an effect on plural-dominant words (t = -2.23), but not on singular-dominant words (t = -1.11).

Lastly, we found a significant three-way interaction between form frequency, number and dominance (t = -2.24). Post-hoc analyses revealed that the aforementioned interaction between form frequency and dominance depends on the number in which the words were presented. Figures 5 illustrates this interaction. There was no effect of form frequency for singular- or plural-dominant words in their singular forms (*bride*, *pea*) and no effect of form frequency for singular-dominant words in their plural form (*brides*). However, there was a significant effect of form frequency for plural-dominant words in their plural form (*peas*, β = -0.156468, t = -1.98).

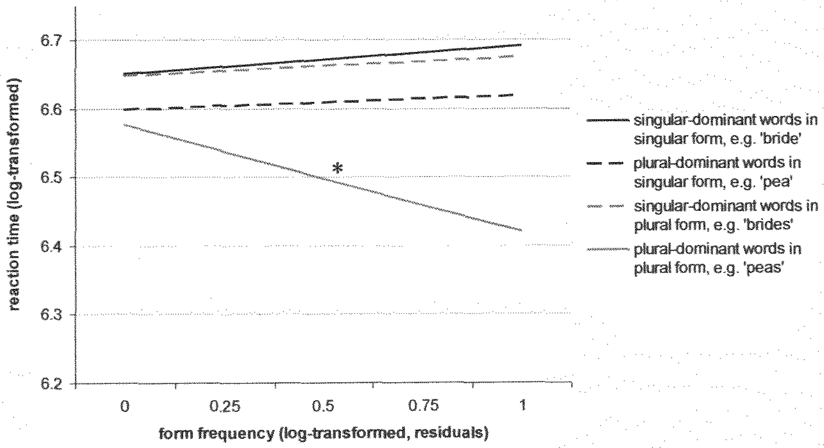


Figure 5: Reaction times for both younger and older people as a factor of form frequency, number dominance, and presented number.

Despite the absence of a form frequency effect for singular forms and singular dominant plural forms, we found effects of lemma frequency for all types of forms.

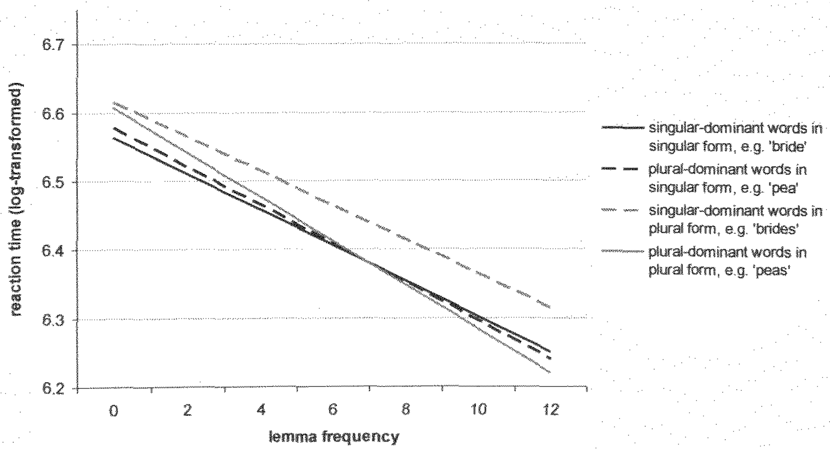


Figure 6: Reaction times for both younger and older people as a factor of lemma frequency, number dominance, and presented number.

Discussion

Using the same materials as Baayen, Dijkstra, et al. (1997) and analyzing the data in two different ways, we largely replicated their findings. The first analysis showed a number-by-dominance interaction such that there was a dominance effect for plural forms but not for singular forms. This is in line with the assumption that reaction times to singular forms are a function of the summed frequency of singular and plural form frequency. Plural forms, however, were only influenced by plural form frequency, leading to longer reaction times for singular-dominant forms and, in turn, to a dominance effect for plural forms only. The explanatory basis for this pattern is a dual-route model in which the decomposition of transparent noun plurals leads to a boost in activation of singular forms and plural forms whenever a plural form is encountered. This results in relatively fast reactions to both singular-dominant and plural-dominant singular forms (*bride*, *pea*), but a difference in reaction time between singular-dominant plural forms (*brides*) and plural-dominant plural forms (*peas*), as the former are parsed and the latter accessed via the storage due to their high frequency.

Secondly, we analyzed the influence of form frequency on reaction times. Form frequency is frequently used as a diagnostic of storage vs. decomposition. Effects of form frequency (in addition to lemma frequency) arise when a form is stored; decomposition, on the other hand, leads to effects of lemma frequency only (Bertram et al., 2000). We found effects of form frequency for plural-dominant words in their plural form (*peas*), indicating that these forms are accessed directly from storage. The other forms did not show form-frequency effects, suggesting that they are accessed via decomposition. This explanation is plausible for the plural forms of singular-dominant words (*brides*). However, we did not find an effect of form frequency for any of the singular forms (*bride*, *pea*) which can only be accessed from storage and should be subject to effects of form frequency.

A possible explanation lies in the high correlation between lemma frequency and form frequency. As mentioned earlier, we regressed form frequency from lemma frequency counts and used the residuals as a measure of form frequency that is free from the influence of lemma frequency. Given the high correlation, it is plausible that the resulting residuals were very small and did not have enough variance to lead to a significant effect of form frequency for singular forms. Future experiments using the continuous nature of frequency need to control for a high correlation between the two frequency measures.

Taking the results from Analysis I and Analysis II together, we find evidence that people can access plural nouns through whole-word access as well as via decomposition. This is in line with predictions made by the parallel dual-route race model (Schreuder & Baayen, 1995) and is in line with previous work on Dutch, Spanish, Italian, and French.

Younger and older people did not differ significantly in their reaction-time pattern, indicating that they processed the stimuli in a similar manner. Based on the results of the four previous verb experiments, we had expected older people to show a different pattern. In the first two chapters, we found evidence suggesting that older people use a more storage-based route to access regular verb inflections, while younger people decompose these forms. We offered two possible explanations for this finding. Firstly, an increase in age means a greater exposure to inflected forms. Past research has shown that high-frequency regular words are stored as whole forms rather than being computed. Following a dual-route approach, this could mean that older people have encountered enough inflected forms to make the storage-based route more efficient than the decompositional route.

Additionally, cognitive decline is likely to slow down the computational processes associated with decomposition. Either or both of these processes may cause older people to access regular inflections as whole words. If the older group used the same approach for nouns as the older participants in our previous experiments with verbs, this would likely have shown in a main effect of dominance, that is, an effect for singular forms as well as for plural forms, as in Table 1. However, a similar pattern for young and old people indicates that both groups decompose transparent plurals in addition to accessing them from storage.

In short, we found a difference between older and younger people in the processing of complex verb forms, but not in the processing of complex noun forms.

Several lines of psycholinguistic research have indicated that lexical category might not just be a linguistic distinction but a real psychological phenomenon. Clinical work reported several cases of double dissociations in which either verbs or nouns were selectively impaired, while the other category appeared spared (Caramazza, & Hillis, 1991; Hillis & Caramzza, 1991; Hart, Berndt, & Caramazza 1985; Warrington & McCarthy, 1983, 1987; Warrington & Shallice, 1984; Miceli, Silveri, Villa, & Caramazza, 1984; Kim & Thompson, 2000; Damasio & Tranel, 1993; Zingeser & Berndt, 1990). This motivated further work with the goal to find distinct neural substrates for these word categories. Results of neuro-imaging studies remain mixed; while several scientists reported selective activation for one category or the other (Perani et al., 1999; Dehaene, 1995; Preissl, Pulvermüller, Lutzenberger, & Birbaumer, 1995; Pulvermüller, Lutzenberger, & Preissl, 1999; Shapiro &

Caramazza, 2003; Tranel, Damasio, & Damasio, 1997), other people have failed to replicate such findings (Warburton et al., 1996; Gomes, Ritter, Tartter, Vaughan, & Rosen, 1997; Osterhout, Bersick, & McKinnon, 1997; Brown, Hagoort, & ter Keurs, 1999). Further, nouns have been shown to be easier to remember than verbs (Wearing, 1973; Thios, 1975; Reynolds & Flagg, 1976), they are acquired at an earlier age (Nelson, 1973; Benedict, 1979), and their naming involves executive functions in a different way and to a different extent, compared to action naming (Shao, Roelofs, & Meyer, 2012). Evidently, nouns are processed differently from verbs, so different findings with regards to their morphological processing are not incompatible with each other.

With respect to the present findings, one might point to three crucial differences between nouns and verbs. Firstly, the verbs used in the previous experiments were significantly more frequent than the nouns in the present experiment (log-transformed form frequency of nouns: $M = 5.48$, log-transformed form frequency of verbs: $M = 6.12$, $t(264) = -2.596$, $p = .01$). As explained in the previous chapters, one of the factors possibly encouraging the older people to access inflected verbs from storage could be the accumulated exposure to these forms over the course of their lifetime. It is conceivable that the nouns used in the current experiment were not frequent enough for the storage-based route to be more efficient for the older participants than the decomposition route. We created a subset of the nouns ($N = 69$) with identical average form frequency compared to the verbs items ($M = 6.13$). However, linear mixed-effects models of the new subset of nouns led to a similar reaction-time pattern. We found an interaction between dominance and presented number ($t = -3.53$). This interaction was present for younger ($t = -3.61$) and older people ($t = -3.24$) alike. Thus, differences in form frequency do not seem to be the basis for differences in processing between verbs and nouns.

The second difference between nouns and verbs concerns the level of the semantic concreteness vs. abstractness. Nouns refer to objects, verbs refer to actions -- or put differently, nouns specify thing-like elements in a referential manner whereas verbs specify relations between these elements in a relational manner (Gentner, 1978). For this reason, nouns are frequently described as more concrete compared to verbs (Breedin, Saffran, & Schwartz, 1998; Marshall, Chiat, Robson, & Pring, 1996; Marshall, Pring, Chiat, & Robson, 1996). Maguire, Hirsh-Pasek, and Golinkoff (2006) propose a continuum in which nouns and verbs are defined by four factors: individuation, shape, concreteness, and imageability. Prototypical nouns fall at the more concrete and highly imageable end of the continuum, while verbs tend to be more abstract. Research has shown the influence of a word's concreteness in a number of different tasks, finding that concrete words are easier and/or faster to process (lexical decision: Bleasdale, 1987; James, 1975; Kroll & Merves, 1986; Schwanenflugel & Shoben, 1983; Whaley, 1978; naming: Bleasdale, 1987; de Groot, 1989; Schwanenflugel & Stowe, 1989; free recall: Paivio, 1986; Schwanenflugel, Akin, & Luh, 1992. For a review, see Schwanenflugel, 1991).Taken together, this difference in ease of conceptualization could in turn mean an advantage for the mental operations associated with nominal inflection compared to verbal inflection. In other words, imagining two *brides* might be easier than imagining having *thought* something in the past. To assess this proposal, we collected concreteness ratings for the noun and verb items on a 7-point scale from 12 naïve participants. Nouns were rated to be significantly more concrete than verbs (5.53 vs. 4.41, $t = 4.524$). The higher difficulty in conceptualizing actions could make storage-based access of verbs more likely for older adults, as a strategy to compensate for cognitive decline. In order to test this hypothesis, we created a subset of the noun data. Removing 43 of the 89 noun items resulted in a data set of equal concreteness ratings compared to the verbs. However, a linear mixed model regression analysis led to a pattern very similar to the pattern of the entire dataset. Importantly, there was an interaction between form frequency, dominance, and number ($t = -2.36$). Form frequency significantly influenced reactions to plural forms of plural-dominant nouns ($\beta = -0.12754$, $t = -4.03$) only; there was no effect of form frequency on any of the other types of forms (singular-dominant plural forms: $t = -1.27$, plural-dominant and singular-dominant singular forms: both $t < 1$). Additionally, younger and older people still showed the same reaction time pattern. Evidently, the differences in concreteness between nouns and verbs did not account for the differences in morphological processing of these two types of inflections.

Lastly, nouns and verbs differ with respect to their morphological complexity. In Dutch, nouns can take a plural marker or a diminutive marker, resulting in four possible forms. Verbs are inflected for number (singular vs. plural), tense (present, past), mood (indicative, imperative, subjunctive), among others. One of the central arguments against decomposition of known words addresses the cognitive costs of continuous on-line computations (Butterworth, 1983). These costs should be greater with increased number of possible forms. Tyler, Bright, Fletcher, & Stamatakis, (2004) found neural activation that is specific for inflected nouns (compared to inflected verbs and uninflected verbs and nouns), concluding that differences in morphological complexity lead to differences in the activation in the brain during morphological processing. As mentioned above, one of the explanations why older people do not seem to decompose regular verbs is the decline in computational efficiency. As nouns are morphologically less complex than verbs, decomposing them might be associated with lower cognitive costs compared to verbal inflections. It is possible that the ease with which inflected nouns can be computed (due to fewer possible computations) leads to preserved decomposition in older people.

In conclusion, it seems that older people decompose transparent plural nouns into their constituent morphemes. In the present experiment, this led to a dominance effect for nouns when presented in their plural number, but no such effect for nouns in their singular form. The basis for this are differences in the factors that influence reactions to singular vs. plural nous (Baayen, Dijkstra et al., 1997): reactions to singular nouns are subject to frequency effects of the singular form; reactions to plural nouns are a function of the summed frequencies of their singular and plural forms. This pattern was unexpected, as previous experiments suggested that older people use whole-word access for regular verbs. We discussed a number of differences between nouns and verbs, especially in terms of frequency, concreteness and productivity. Further research is necessary to determine why affected the processing of verbs but not of nouns.

Appendix

Table A1: List of all target items.

Items		Frequency (log-transformed) Lemma	Form SG	Form PL	Dominance	Gloss	Average RT SG	Average RT PL	Average accuracy SG	Average accuracy PL
ambt	ambten	6.41	6.18	4.81	singular	office	612	642	0.89	0.95
baai	baaien	6.37	6.31	3.50	singular	bay	630	623	0.96	0.83
bruid	bruiden	6.12	6.07	3.00	singular	bride	592	613	1.00	0.96
buik	buiken	7.99	7.95	4.58	singular	belly	607	621	1.00	0.96
drank	dranken	7.41	7.23	5.63	singular	drink	528	587	1.00	1.00
dwerg	dwergen	5.67	5.05	4.89	singular	gnome	590	589	1.00	1.00
eend	eenden	6.81	6.21	6.00	singular	duck	542	568	1.00	1.00
eeuw	eeuwen	9.17	8.97	7.47	singular	century	604	634	0.96	0.96
feit	feiten	9.31	9.06	7.80	singular	fact	581	606	1.00	0.96
fout	fouten	7.65	6.97	6.95	singular	fault	586	594	1.00	1.00
fuik	fuiken	4.44	4.17	3.00	singular	fyke	630	677	0.96	0.78
galg	galgen	5.06	4.93	2.94	singular	gallows	647	673	0.88	0.87
gang	gangen	8.97	8.87	6.61	singular	passage	566	627	0.96	0.96
havik	haviken	5.01	4.78	3.43	singular	vulture	668	663	0.74	0.81
helft	helften	8.15	8.11	5.00	singular	half	549	654	0.96	0.93
hemd	hemden	6.91	6.77	4.91	singular	shirt	586	665	1.00	0.96
hoofd	hoofden	10.04	9.99	7.01	singular	head	614	604	0.96	0.96
huid	huiden	8.20	8.18	4.56	singular	skin	554	636	1.00	0.89
kast	kasten	7.53	7.33	5.83	singular	cupboard	548	607	1.00	1.00
kelk	kelken	4.94	4.74	3.26	singular	goblet	655	782	0.77	0.74
kern	kernen	7.52	7.31	5.83	singular	core	616	653	0.91	0.89
klerk	klerken	4.81	4.53	3.40	singular	clerk	704	791	0.68	0.52
korps	korpsen	5.07	5.01	2.20	singular	corps	692	737	0.96	0.82
lakei	lakeien	4.79	4.19	3.99	singular	lackey	715	741	0.78	0.87
lont	lonten	4.79	4.69	2.40	singular	fuse	708	757	0.74	0.59
mouw	mouwen	6.96	6.38	6.13	singular	sleeve	645	619	0.96	0.96
muil	muilen	4.96	4.85	2.71	singular	mule	693	759	0.81	0.65
muts	mutsen	5.70	5.50	3.99	singular	hat	649	656	0.91	0.89
nest	nesten	6.90	6.70	5.19	singular	nest	619	599	0.95	0.96
park	parken	7.39	7.21	5.61	singular	park	594	597	1.00	0.93
part	parten	5.70	5.31	4.56	singular	part	689	735	0.81	0.91
plein	pleinen	7.08	6.95	5.00	singular	square	576	663	1.00	0.91
pond	ponden	6.47	6.34	4.38	singular	pound	613	744	0.91	0.67
prei	preien	4.99	4.96	1.39	singular	leek	617	681	0.96	0.85
pruik	pruiken	5.66	5.41	4.14	singular	wig	594	573	1.00	0.96
romp	rompen	6.26	6.22	3.09	singular	trunk	610	668	1.00	1.00
sprei	spreien	5.00	4.90	2.71	singular	(bed) spread	639	693	0.96	0.86
stijl	stijlen	7.64	7.57	4.92	singular	style	563	619	1.00	1.00
soep	soepen	6.89	6.83	4.16	singular	soup	606	607	1.00	0.96
telg	telgen	4.32	4.14	2.48	singular	descendant	648	718	0.74	0.65
term	termen	8.23	7.57	7.49	singular	term	597	655	0.87	1.00
tijd	tijden	10.67	10.61	7.87	singular	time	547	593	1.00	0.96
tong	tongen	7.72	7.64	5.19	singular	tongue	581	604	0.96	1.00
valk	valken	5.99	5.72	4.54	singular	falcon	563	608	1.00	0.89
voogd	voogden	6.69	6.66	3.37	singular	guardian	626	693	1.00	0.85
vork	vorken	6.21	6.05	4.26	singular	fork	596	666	1.00	1.00
wand	wanden	7.54	6.95	6.74	singular	wall	621	632	1.00	1.00
zalm	zalmen	5.37	5.24	3.26	singular	salmon	577	598	0.96	0.91
zeug	zeugen	4.33	4.22	2.08	singular	sow	673	705	0.65	0.78
berk	berken	5.04	4.29	4.39	plural	birch	702	671	0.87	0.88

Items		Frequency (log-transformed) Lemma	Form SG	Form PL	Dominance	Gloss	Average RT SG	Average RT PL	Average accuracy SG	Average accuracy PL
biet	bieten	4.88	3.81	4.45	plural	beet	727	701	0.70	0.91
boeg*	boegen	5.86	1.10	5.85	plural	bow (naut.)	---	---	0.95	0.48
darm	darmen	6.40	5.64	5.77	plural	intestine	571	581	0.96	1.00
dier	dieren	8.92	8.11	8.32	plural	animal	578	563	1.00	0.96
duin	duinen	6.41	4.73	6.20	plural	dune	672	633	0.86	0.93
erwt	erwten	5.16	3.81	4.87	plural	pea	628	587	1.00	0.96
flank	flanken	5.61	4.58	5.16	plural	flank	742	711	0.74	0.87
friet	frieten	4.30	3.53	3.69	plural	(french) fry	638	664	0.96	0.91
gast	gasten	7.78	6.67	7.38	plural	guest	548	544	1.00	1.00
geit	geiten	6.00	5.09	5.48	plural	goat	602	581	0.96	0.96
gift	giften	5.49	4.49	5.04	plural	gift	588	634	1.00	0.93
halm	halmen	4.30	3.43	3.76	plural	stalk	695	769	0.50	0.41
heup	heupen	6.88	5.59	6.56	plural	hip	626	567	0.96	1.00
kaars	kaarsen	6.73	6.00	6.08	plural	candle	544	531	1.09	1.00
kers	kersen	5.29	3.71	5.06	plural	cherry	636	587	0.78	0.96
klant	klanten	7.65	6.77	7.11	plural	customer	581	555	0.96	0.96
klomp	klompen	6.24	5.22	5.80	plural	clog	625	629	1.00	0.91
kluit	kluiten	4.52	0.00	4.51	plural	lump	695	696	0.83	0.89
kous	kousen	6.27	5.00	5.94	plural	stocking	670	664	0.78	0.91
kuit	kuiten	5.78	4.53	5.44	plural	calf	644	667	0.89	0.96
loep*	loepen	5.10	0.00	5.10	plural	magn. glass	---	---	0.82	0.37
long	longen	6.76	5.31	6.49	plural	lung	633	628	0.74	0.87
maand	maanden	9.18	8.05	8.79	plural	month	536	552	1.00	0.96
meeuw	meeuwen	6.10	5.07	5.67	plural	seagull	621	616	1.00	0.96
mens	mensen	10.97	9.82	10.59	plural	human	538	540	1.00	0.96
nier	nieren	6.13	4.77	5.83	plural	kidney	614	643	0.89	0.95
norm	normen	7.95	6.31	7.73	plural	norm	598	650	1.00	0.96
plank	planken	7.18	6.39	6.57	plural	plank	556	594	1.00	1.00
pont*	ponten	5.14	1.79	5.10	plural	ferryboat	---	---	0.65	0.44
rots	rotsen	7.31	6.44	6.76	plural	rock	558	592	1.00	0.96
rups	rupsen	4.84	3.97	4.29	plural	caterpillar	652	691	0.85	0.91
stoet*	stoeten	6.21	3.18	6.16	plural	procession	---	---	1.00	0.49
twijg	twijgen	5.03	3.69	4.73	plural	twig	684	728	0.91	0.70
voet	voeten	9.16	8.31	8.60	plural	foot	552	545	1.00	1.00
wang	wangen	7.94	7.08	7.40	plural	cheek	624	630	0.93	0.87
welp	welpen	3.91	1.61	3.81	plural	cub	640	663	0.96	1.00
wesp	wespen	5.15	4.34	4.56	plural	wasp	612	568	1.00	1.00
wilg	wilgen	4.84	3.69	4.47	plural	willow	627	636	0.96	0.81
wolk	wolken	7.62	6.45	7.25	plural	cloud	553	539	0.96	1.00
woord	woorden	10.13	9.39	9.48	plural	word	590	568	1.00	1.00
worm	wormen	5.90	4.76	5.52	plural	worm	579	609	1.00	0.96
zenuw	zenuwen	6.99	4.32	6.91	plural	nerve	607	631	1.00	1.00
zuil	zuilen	6.51	5.47	6.08	plural	pillar	619	619	1.00	0.91

* Excluded due to low accuracy

Inflectional processing in a morphologically rich language: German noun plurals

Chapter 5

Abstract

Whether a morphologically complex word is decomposed into its constituents or accessed as a full form depends on a number of factors. While researchers have studied the influence of linguistic properties of the stem (e.g., frequency, regularity) and the affix (e.g., productivity, homonymy), broader linguistic factors such as the morphological richness of the language have rarely been considered. The present study investigated the processing of noun plurals in German, a language with rich noun morphology.

Additionally, the study included two different age groups. In previous experiments, we found evidence that older people accessed morphologically complex Dutch past-tense verbs as full forms, while they showed effects of both decomposition and storage for Dutch plural nouns.

We tested 25 younger (19-26 years) and 15 older (60-73 years) participants in a lexical decision task. The materials were singular and plural forms of singular-dominant and plural-dominant nouns from four different German plural paradigms. The overall pattern that emerged showed a main effect of age, a main effect of presented number, no interaction between dominance and number, and no effect of form frequency. This indicates that speakers of German access plural nouns via decomposition and not from the storage.

The processing of morphologically complex words has been a highly debated topic for the better half of the last century. The basic question is whether words consisting of two or more morphemes are stored as whole forms, or whether these complex forms are computed on-line by accessing and combing the constituents. The former view is known as full listing (Butterworth, 1983), the latter is called full decomposition or full parsing (see e.g. Taft & Forster, 1975; Taft, 1979; Taft, 2004). Lately, studies have moved away from all-or-nothing approaches; instead, many models of morphological processing acknowledge the existence of both decomposition and full-form storage (e.g., dual-route race model, Schreuder & Baayen, 1995). The focus has moved to determining the factors that influence whether morphologically complex words are parsed or stored. The factors that have been established are mainly of linguistic nature.

There seems to be a basic distinction between derivations and inflections, with the former having a higher likelihood to be stored as full forms (Stanners, Neiser, Hernon, & Hall, 1979; Niemi, Laine, & Tuominen, 1994; Schriefers, Friederici, & Graetz, 1992; Taft, 1994). This distinction is not surprising, given that derivational morphology often changes the meaning and/or the syntactic function of a word, while inflections serve grammatical purposes (Marslen-Wilson, Tyler, Waksler, & Older, 1994). Further, studies have found that regularity plays an important role. Regular inflected forms (i.e., predictable through a rule) are usually parsed, whereas irregular (i.e., unpredictable) forms are stored (Pinker & Ullman, 2002; Prasada, Pinker, & Snyder, 1990). Productivity and homonymy of the affix also play an important role for the processing of morphologically complex forms. Bertram and colleagues showed that derived Finnish and Dutch words with an unambiguous, productive affix were recognized faster than monomorphemic words, while complex words with an ambiguous or unproductive affix were recognized as fast as morphologically simple words (Bertram, Laine, & Karvinen, 1999; Bertram, Schreuder, & Baayen, 2000). This was taken as evidence that productivity as well as ambiguity affects morphological decomposition. Further linguistic factors are frequency (with higher frequency leading to storage, Alegre & Gordon, 1999; Lehtonen & Laine, 2003; Soveri, Lehtonen, & Laine, 2007; Lehtonen, Niska, Wande, Niemi, & Laine, 2006), semantic transparency (Marslen-Wilson et al., 1994, Feldman & Soltano, 1999, but see Roelofs & Baayen, 2002; Lüttmann, Zwitserlood, & Bölte, 2011; Andrews & Lo, 2013), and the existence of past-tense doublets for which a regularized form exists next to an irregular form, such as *dived* vs. *dove* (Ullman, 1993).

All of these factors concern differences between different types of morphological processes and properties of stems and affixes within one language. However, languages vary greatly with respect to their morphological complexity. English, which is the basis for the majority of well-known theories on morphological processing, is on the less complex end of the continuum. There is one regular plural affix *-s* for nouns and there are only few regular verbal affixes, such as *-s*, *-ed*, and *-ing*. Finnish, on the other hand, possesses over 10000 possible forms for each verb and over 2000 inflectional variants for each noun due to a large number of inflectional paradigms and grammatical categories that are expressed through affixes (Karlsson & Koskenniemi, 1985). This leads to the question whether the morphological richness of a language influences the degree to which regular inflected forms are stored. And if so, does a high number of possible inflections lead to more storage or to less storage?

Arguments exist for both hypotheses. Frauenfelder and Schreuder (1992) described the two opposing principles, economy of storage and economy of processing. The economy of processing constraint claims that retrieving a full form is easier than parsing it. For a morphologically rich language, this seems applicable to both production and comprehension of morphologically complex words. On the production side, extensive storage seems like a logical consequence when a speaker is confronted with a wide variety of plural types, especially if it is arbitrary to which paradigm a given word belongs. How is the speaker to know which affix goes with which stem? In addition to applying the computational rule, the processing system would also need to store information about which rule is applied. As for comprehension, a morphologically rich language often provides the issue of homographic and homophonic affixes with different purposes and meanings. Instead, a direct access to the full forms seems like a plausible option.

The economy of storage constraint, on the other hand, points to limitations of the memory system. One might argue how uneconomic such a reliance on full storage would be, especially in a morphologically rich language. Storing a great number of possible forms per lexeme – most of which will be accessed relatively infrequently – in the mental lexicon seems an unlikely option. Hankamer (1989) argues against full-listing in morphologically rich agglutinative languages such as Turkish. This is based on calculations that the mental lexicon of an adult speaker would have to contain over 200 billion entries, which the author claims exceeds the storage capacity of the brain.

The experimental studies that addressed inflectional morphology in a morphologically rich language like Finnish have indeed found hardly any evidence for storage of inflected forms (Bertram et al., 1999). Niemi et al. (1994) compared lexical decisions for uninflected and inflected nouns and found higher latencies for inflected forms. The authors argue that inflected nouns are subject to morphological decomposition, leading to longer reaction times. Similar effects of processing cost have been found for eye movement patterns (Hyönä, Laine, & Niemi, 1995), recognition of progressively demasked stimuli (Laine, Vainio & Hyönä, 1999), and reading errors in aphasia (Laine, Niemi, Koivuselkä-Sallinen, Ahlsén, & Hyönä, 1994; Laine, Niemi, Koivuselkä-Sallinen, & Hyönä, 1995). This is in contrast to previous work on Dutch (Baayen, Dijkstra, & Schreuder, 1997; Baayen, McQueen, Dijkstra, & Schreuder, 2003; Chapter 4 of this thesis), French (New, Brysbaert, Segui, Ferrand, & Rastle, 2004), Spanish (Dominguez, Cuetos, & Segui, 1999), Italian (Baayen, Burani, & Schreuder, 1997), and English (Sereno & Jongman, 1997) which showed evidence for storage of plural forms of plural-dominant nouns (e.g. *peas*). Compared to Finnish, none of these languages possesses a rich noun morphology. Dutch has two regular plurals (*-en*, *-s*, plus about 10 nouns taking *-eren* as a plural suffix), as does Italian (*-i* and *-a*). Spanish has only one regular paradigm (*-s*, or *-es* if the stem ends in a consonant), as does French (*-s*, or *-aux* for words ending in *-al*, plus a few irregular nouns). None of these languages inflects their nouns for case. Given the different findings for these languages compared to Finnish, it is of importance to consider cross-linguistic differences as a factor influencing the trade-off between decomposition and storage. The present study addresses this issue by investigating the processing of noun plurals in German.

German plurals

German inflects nouns for case (nominative, genitive, dative, accusative) and number (singular, plural). There are five[12] different plural affixes, *-Ø*, *-(e)n*, *-e*, *-er*, and *-s*. Some of these allow for ablauting through fronting of the stressed vowel in the stem. Linguists have attempted to determine patterns that predict a word's plural from its phonology, grammatical gender, or semantics, but the list of exceptions to such

[12] In the present study, we include only phonologically salient plural affixes

rules is usually quite long (Köpcke, 1988; Mugdan, 1977). The only rule without exception is that feminine nouns ending in [«] take *-n* as their plural affix. By and large, it seems that the type of plural a word takes is arbitrary. See Table 1 for an overview of all plural affixes.

Table 1: German plural affixes. Size is the estimated percentage of words within a paradigm (Clahsen, 1999)

Type	Size	Ablaut	Example	Gloss
-Ø	---	Yes, not predictable	Krater	crater(s)
			Vater → Väter	fathers
-er	2-8 %	Yes, always for back vowels	Huhn → Hühner	chickens
-s	2-8 %	No	Zebra → Zebras	zebras
-e	22-33 %	Yes, not predictable	Kuh → Kühe	cows
			Hund → Hunde	dogs
-(e)n	53-68 %	No	Katze → Katzen	cats

Linguists have debated the existence of a regular plural morpheme in German. Despite its infrequence, it has been argued that the *-s* plural affix is the regular plural morpheme (Clahsen, Rothweiler, Woest, & Marcus, 1992; Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1993; Clahsen, 1999). Indeed, there is some evidence for its status as the default morpheme. *-s* is used as the "emergency plural ending", that is, when the phonological environment does not allow for another affix. Proper names (even those homophonous with existing nouns, e.g. *Bach*), clippings (e.g. *Loks*, clipped form of *Lokomotiven*, 'locomotives'), onomatopoeic nouns, nonce words, and acronyms usually take on the *-s* affix.

However, Bybee (1995) claims that the default status of the *-s* plural is not due to the application of a rule, but that it functions rather like a lexical schema and is thus affected by existing items. Developmental studies have found mixed results; while some present evidence that children primarily overgeneralize *-s* (Clahsen et al., 1992; Clahsen, Marcus, & Bartke, 1993), others find that more overgeneralizations with *-(e)n* (Mills, 1985; Park, 1978). Loan words take either *-(e)n* and *-s*, largely depending on their grammatical gender (Köpcke, 1988).

Behavioral data support the assumption that *-s* plurals are regular and parsed, while *-er* plurals are irregular and stored (lexical decision: Clahsen, Eisenbeiss, & Sonnenstuhl-Henning, 1997; cross-modal priming: Sonnenstuhl, Eisenbeiss, & Clahsen, 1999). One problem with these behavioral findings is that *-s* plurals were compared with only the *-er* affix (to hold type frequency between the different plural types constant), but not with the other plural affixes.

Neuroimaging studies further suggest a special status of the *-s* affix. Beretta et al. (1999) report an fMRI study showing differences in neural activation evoked by regular vs. irregular verbs and nouns (contrasting *-er* plurals with *-s* plurals). However, the authors did not distinguish between verbs and nouns and did not compare activation for *-s* plurals with *-e* or *-(e)n* plurals, so it is hard to draw clear conclusions from this study. Weyerts, Penke, Dohrn, Clahsen, and Münte (1997) compared brain potentials evoked by violations through "regularizations" (**Muskel-s* instead of *Muskel-n*, 'muscles') to violations through "irregularizations" (**Karussell-en* instead of *Karussell-s*, 'merry-go-rounds'). They found different patterns of neural activation for the two processes, which the authors took as evidence in favor of *-s* as the regular plural affix.

It seems that the *-s* plural affix is indeed special compared to at least *-er* plurals. However, it is unclear if this special status necessarily means that it is the (only) regular plural morpheme in German.

The influence of age

In Chapters 2 and 3, we established age as a factor influencing morphological processing. Contrasting a student population with speakers over the age of 60, we found that the younger people decomposed Dutch regular past-tense verbs, while older people accessed them as whole words. In Chapter 4, on the other hand, we did not find age differences in the processing of Dutch plural nouns. Instead, younger and older participants parsed the plural forms of singular-dominant nouns (e.g. *brides*) and accessed the plural forms of plural-dominant nouns (e.g. *peas*) from storage. We considered differences in concreteness, frequency, and morphological complexity between nouns and verbs as possible reasons for the different findings. Including a sample of older participants in the present study might help us understand the influence of age: Do speakers of a morphologically rich language change the way they process these words over the course of their life?

The present study aims to address two questions. First, to what extent and in what way does morphological richness play a role in morphological processing? Are plural nouns stored because their plural affix is largely arbitrary? Or are they decomposed into stem + affix because of the great number of possible forms?

Second, does age play a role for the processing of German plurals? Do older people access complex forms as whole words (as they did with Dutch verbs in Chapters 2 and 3), or do they decompose these forms (like the older participants did in Chapter 4)?

As in Chapter 4, we contrasted lexical decisions to singular and plural forms of singular-dominant forms (singular form frequency > plural form frequency, e.g. *bride* vs. *brides*) and plural-dominant forms (singular form frequency < plural form frequency, e.g. *pea* vs. *peas*). We used two ways of analyzing responses to target words. In the first analysis, we compared reaction times for singular and plural forms of singular-dominant words (*bride* vs. *brides*) to reaction times for singular and plural forms of plural-dominant words (*pea* vs. *peas*). According to the parallel dual-route race model by Schreuder and Baayen (1995), the reaction times to a *singular* form are a factor of the summed frequency of the singular and plural form. The recognition time for a plural form, however, is determined by its plural form frequency alone. The reason for this is that whenever a plural form is encountered, this will lead to a boost in activation for the according singular form as well. In a lexical decision task, this means that when a written or spoken word is processed, two processes (decomposition and whole-word access) are active at the same time. Whichever route is faster will lead to a lexical decision. Plural forms of singular-dominant forms (*brides*) are accessed via decomposition due to their low form frequency, leading to longer reaction times for their plural forms compared to their singular forms (*bride* < *brides*). The plural forms of plural-dominant forms, on the other hand, are frequent enough to be accessed from storage. This means that reaction times to plural-dominant plural forms (*peas*) are as fast as reactions to their corresponding monomorphemic singular forms (*pea*), which profit from the high frequency of their plural form (*pea* = *peas*). This leads to the interaction between dominance and presented number that has been observed previously.

The second analysis is a more direct way of investigating storage via form-frequency effects. Form frequency is a common diagnostic tool to investigate storage. If a form is accessed as a whole word from the mental lexicon (rather than decomposed), we expect effects of both form frequency and lemma frequency to influence reaction times. If form frequency does not influence reaction times, this indicates that the form in question is not stored but decomposed instead (Bertram, Schreuder, & Baayen, 2000). Compared to Analysis I, this analysis uses the continuous nature of form frequency as a predictor instead of just dichotomous factors like dominance.

Figure 1 illustrates how reaction-time patterns allow us to draw conclusions about the processes leading to a lexical decision.

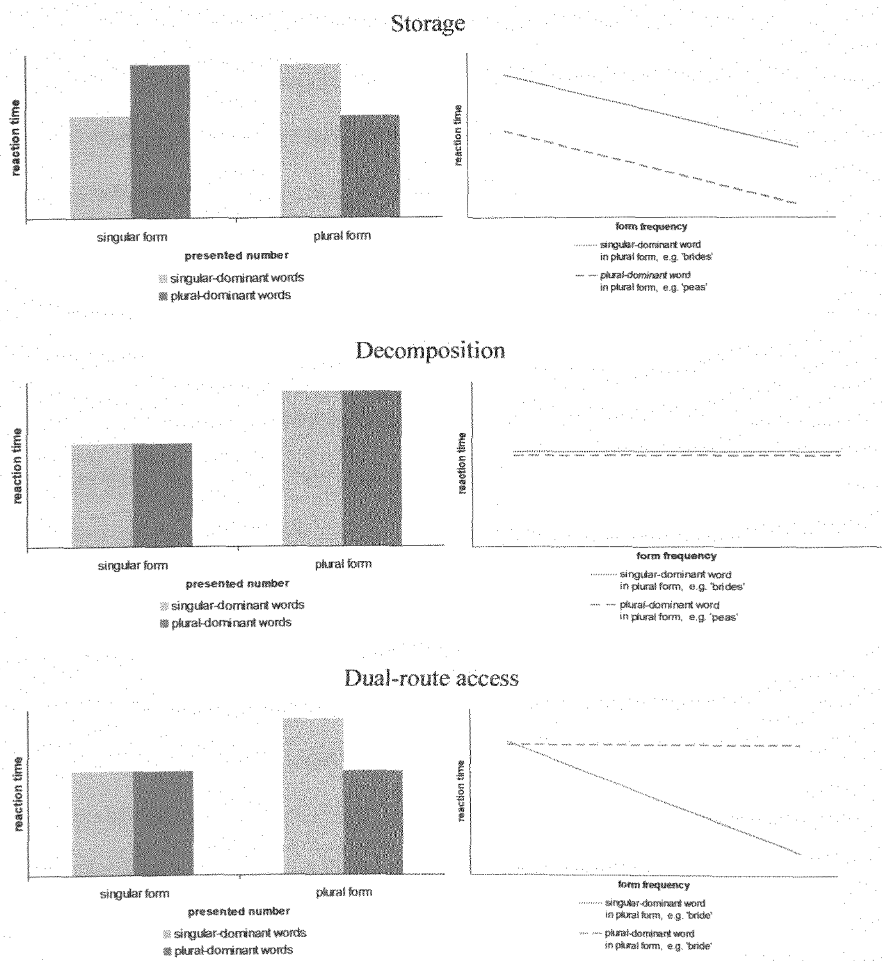


Figure 1: Overview of predicted reaction time patterns.

If complex forms are accessed from storage, we expect the plural forms of singular-dominant forms to yield slower responses than their singular forms (*bride* < *brides*) because their form frequency is lower and the plural forms of plural-dominant forms to yield faster responses than their singular form (*pea* > *peas*). Similarly, storage will be indicated through faster responses to both plural forms as a function of form frequency.

If plural forms are decomposed into their stem and an affix, we expect a main effect of presented number, with responses to both singular-dominant and plural-dominant plural forms being slower than responses to their respective singular forms. If there is decomposition instead of storage, we should not find an effect of form frequency, but only of lemma frequency.

Lastly, dual-route models predict a combination of the two accounts. The plural forms of singular-dominant words (*brides*) are accessed via decomposition, leading to an effect of presented number for Analysis I, but no effect of form frequency in Analysis II. The plural forms of plural-dominant words (*peas*) are accessed from storage, so responses to these forms are as fast as responses to their singular forms (i.e., no effect of presented number); additionally, the access from the storage leads to an effect of form frequency for plural-dominant plural forms only.

Our design includes form frequency (continuous), lemma frequency (continuous), presented number (singular vs. plural), and dominance (singular-dominant vs. plural-dominant) as within-subjects factors and age (young vs. old) as between-subjects factor.

Method

Participants

The younger age group consisted of 25 participants (22 female, no left-handed, $M_{Age} = 21$, $range_{Age} = 19\text{-}26$), all of whom were students at Westfälische Wilhelms-Universität Münster. The older age group consisted of 15 participants (11 female, no left-handed, $M_{Age} = 66$, $range_{Age} = 60\text{-}73$) living in Münster or Kranenburg. All participants reported having normal or corrected-to-normal vision and were either paid for their participation or received course credit. All participants provided informed consent to participate in the study and all data were analyzed anonymously.

Materials

The entire set of stimuli consisted of 542 German words and 542 pseudowords, which were created by changing one phoneme (usually a vowel) of the existing words.

The 271 singular and their corresponding 271 plural forms were split into eight groups according to their plural type, and to whether they were singular- or plural-dominant. 11% of the targets were translation equivalents of the items used in Chapter 3. Table 2 provides an overview of the stimulus categories and Table A1 in the Appendix shows the entire list of stimuli. Within each plural category, the items were matched for lemma frequency (Mannheim word frequency as reported in CELEX, Baayen, Piepenbrock, & Gulikers, 1995).

Table 2: Overview of the stimuli categories.

Type			Frequency			N	
			Form		Lemma		
			Singular	Plural		presented	included
Target items							
	-(e)n plurals	singular-dom.	3.55	2.09	3.72	89	70
		plural-dom.	2.26	3.21	3.58	89	72
	-e plurals	singular-dom.	4.41	2.57	4.69	27	23
		plural-dom.	3.08	4.01	4.64	27	23
	-er plurals	singular-dom.	5.48	3.81	5.93	6	6
		plural-dom.	3.47	4.57	5.13	6	6
	-s plurals	singular-dom.	3.88	2.57	4.15	13	7
		plural-dom.	2.90	3.51	3.98	13	6
						271	213
Filler items	Adjectives, adverbs					271	
Pseudowords	Phoneme-changed versions of the target and filler items					542	
Total						1084	

The stimulus material was divided over two lists of 1084 items each, so that participants saw only one form per item, either its singular or its plural form. Half of the participants saw list a, the other half saw list b.

Apparatus

The experiment was programmed using Presentation® (version 14.7, Neurobehavioral Systems, USA). The items were presented in black upper case letters (Arial font size 48) against a white background.

Procedure

All participants were tested individually and were instructed by the experimenter as well as by a standard set of instructions on the computer screen.

There were ten experimental blocks with 100 items each and a last block with 84 items. The first experimental block was preceded by ten practice trials. Participants were allowed to take short breaks after the practice block and between test blocks.

In every trial, first, a fixation cross "+" appeared on the screen for 600 ms, after which the test item appeared for 2600 ms. The experiment was quasi-self-paced; items disappeared after the first response. There was no feedback on accuracy.

Results

58 items received fewer than 50% correct reactions, so both the singular and the plural form were excluded from further analyses (12.3% of the items, see Appendix). Further, trials with reaction times longer than 2.5 SDs from the mean and shorter than 300 ms were discarded on a per-subject basis as were trials with incorrect lexical decisions, which resulted in the exclusion of 5.2% of the data. No participants were excluded.

We calculated Linear Mixed Effects Models, using the languageR package (Baayen, 2007) and the lme4 package (Bates, 2005; R Development Core Team, 2011). For Analysis I (following the original analysis by Baayen, Dijkstra et al., 1997), we established the model that best explains log-transformed reaction times on the basis of the independent factors of the items (dominance, lemma frequency, presented number, plural type) and the subjects (age). Analysis II included the same factors and form frequency as an additional independent factor. The fixed factors (except for plural type) were centered. In order to avoid multicollinearity, we regressed form frequency from lemma frequency and used the residuals as a measure of form frequency. This ensures that form frequency effects reported here are free from confounding influences of lemma frequency. However, as there were no significant effects of form frequency, both analyses yielded the same best model.

Table 3: The model that best explains overall reaction times to noun plurals

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.5341	0.0259	252.27	< .001
age	0.1790	0.0359	4.99	< .001
lemma frequency	-0.0258	0.0032	-8.14	< .001
number	0.0441	0.0081	5.47	< .001
plural type.en	0.0189	0.0102	1.85	< .1
plural type.e	0.0233	0.0125	1.87	< .1
plural type.er	0.0489	0.0226	2.17	< .05

Random Factors	Name	Variance explained	Standard Deviation	Correlation	
noun	intercept	0.0045	0.0670		
	age	0.0021	0.0458	0.11	
subject	intercept	0.0215	0.1465		
	lemma frequency	0.0001	0.0098	-0.73	
	number	0.0002	0.0016	0.73	-0.88
Residual		0.0295	0.1717		

Age had a main effect on reaction times ($t = 4.99$); young people had shorter reaction times than older people (591 ms vs. 710 ms). There was a main effect of lemma frequency; more frequent words lead to shorter reaction times ($\beta = -0.0258$, $t = -8.14$). Number influenced lexical decisions ($t = 5.47$); responses to singular forms were faster than responses to plural forms (622 ms vs. 651 ms). There was no effect of form frequency and no interaction between dominance and presented number (both $t < 1$).

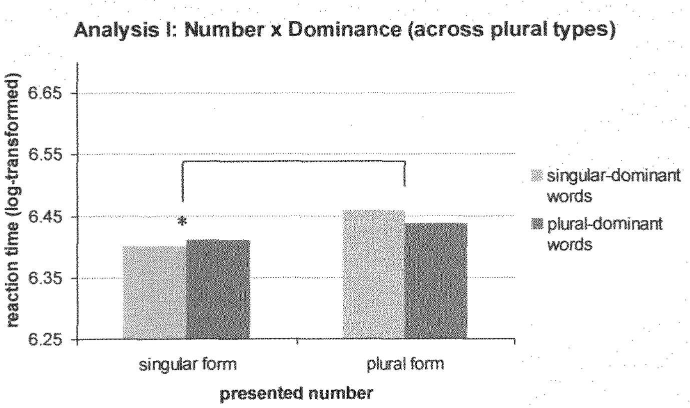


Figure 2: Reaction times of all participants broken down by presented number and dominance.

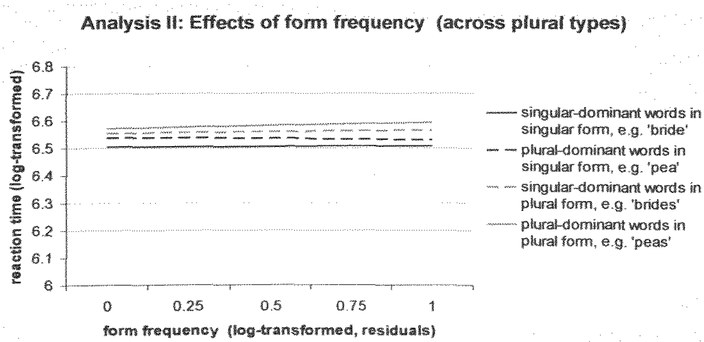


Figure 3: Reaction times as a function of form frequency, presented number, and dominance.

As mentioned in the Introduction, the four plural types used in this study have different properties. There are differences with respect to type and token frequency, which is reflected in the different sample sizes and differences in lemma frequency for the plural types. As indicated in Table 3, plural type influences reaction times.

Including plural type as a fixed factor significantly improved model fit (χ^2=10.363, p = .02). For this reason, we split the data by age and by plural type. Figures 4 and 5 provide an overview of the reaction times by younger and older people split by the different plural types.

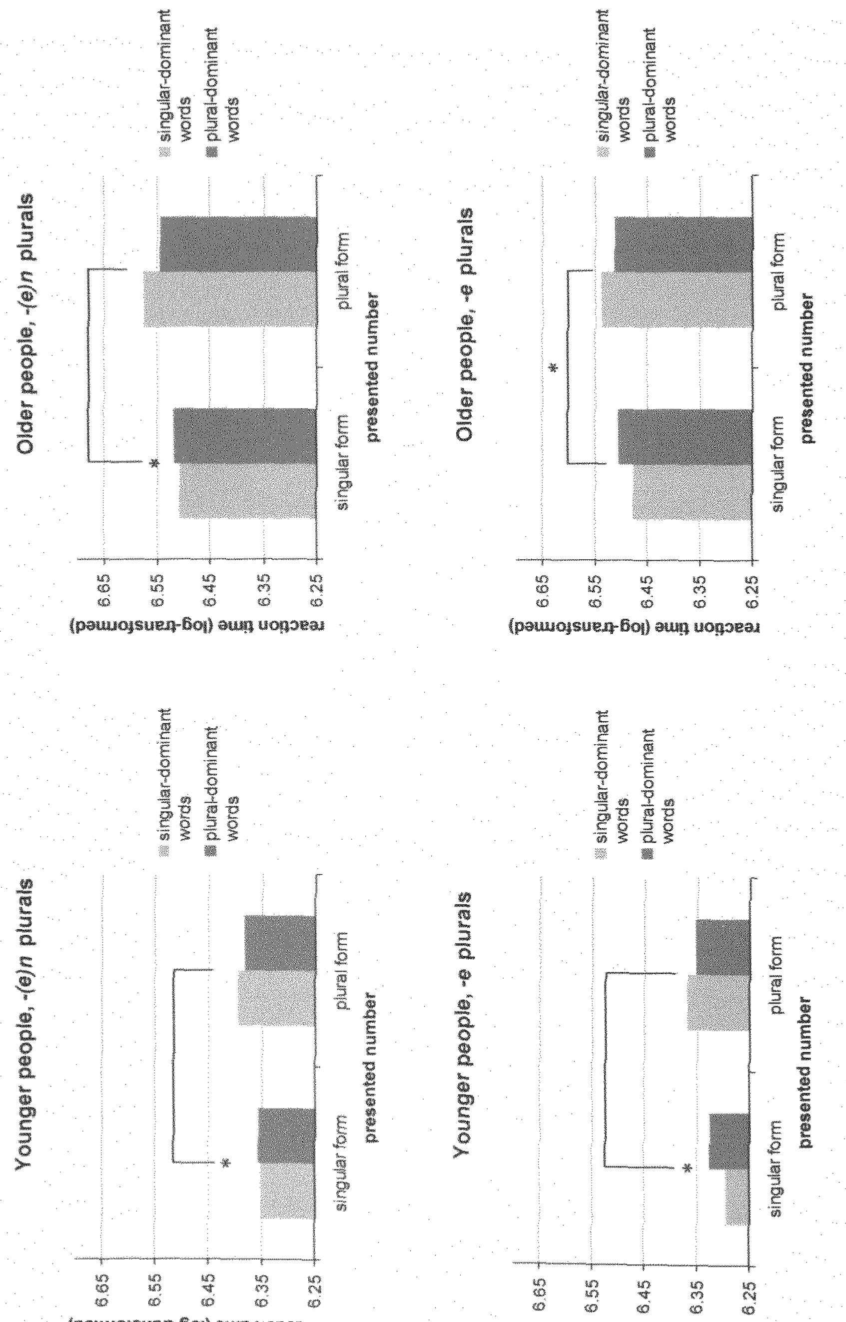


Figure 4: Reaction times of younger and older people broken down by number and dominance.

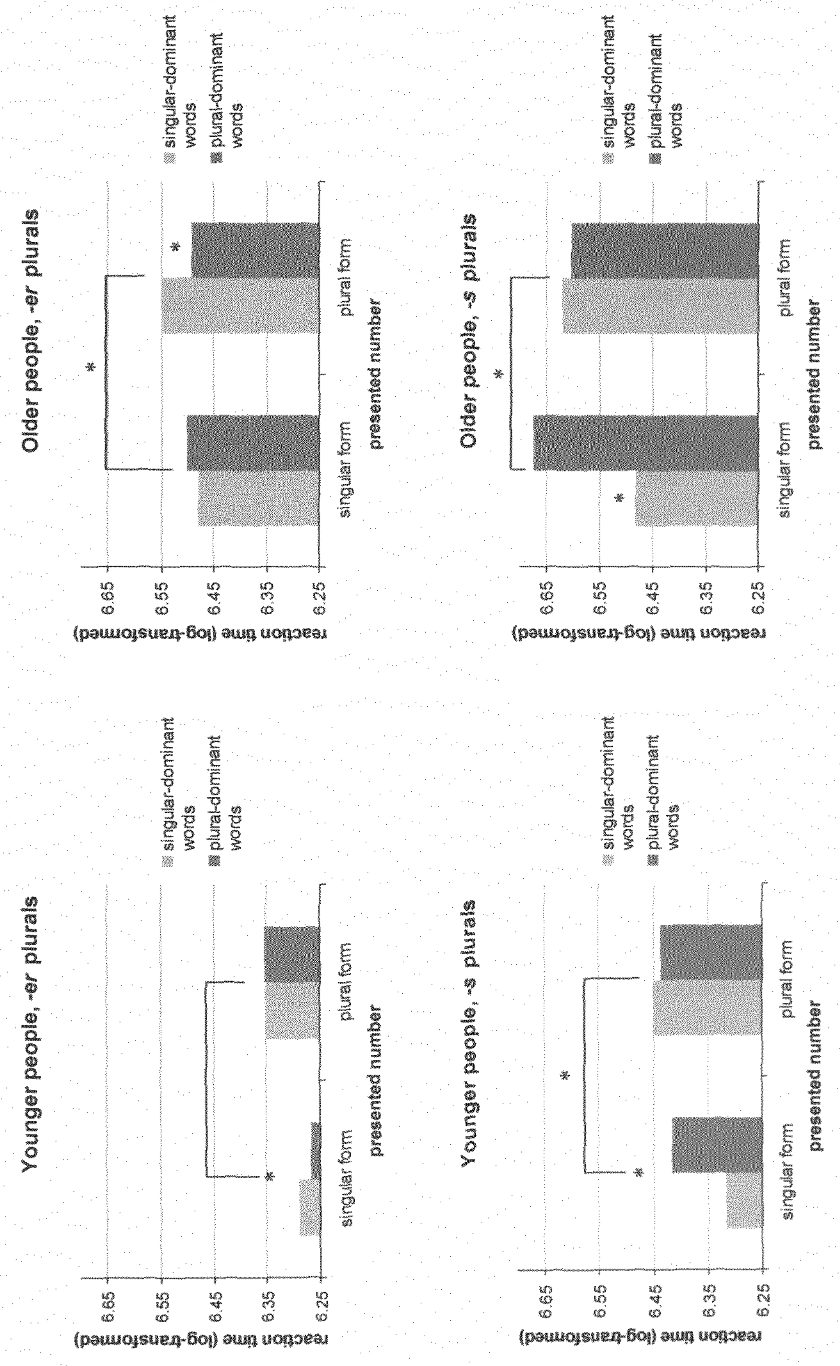


Figure 5: Reaction times of younger and older people broken down by number and dominance.

Given the different reaction-time patterns that emerged (illustrated in Figures 4 and 5), we split the data by plural type and age to investigate the influences of the independent factors for each plural type separately.

Analysis I: Number x Dominance

-(e)n plurals.

Overall pattern.

Table 4: The model that best explains overall reaction times to *-(e)n* plurals.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.6591	0.0370	180.15	< .001
age	-0.1621	0.0423	-3.83	< .001
lemma frequency	-0.0283	0.0040	-7.04	< .001
number	-0.0391	0.0052	-7.46	< .001

Random Factors	Name	Variance explained	Standard Deviation	Correlation	
noun	intercept	0.00665272	0.081564		
	age	0.00259036	0.050896	-0.47	
	number	0.00036941	0.019220	-0.97	0.67
subject	intercept	0.01637500	0.127965		
Residual		0.03014114	0.173612		

There were 142 items with *–(e)n* plurals. Age had a main effect on reaction times ($t = -3.83$); younger people had shorter reaction times than old people (599 ms vs. 712 ms). There was a main effect of lemma frequency, with more frequent words leading to shorter reaction times ($\beta = -0.028309$, $t = -7.04$). Presented number influenced lexical decisions ($t = -7.46$); responses to singular forms were faster than responses to plural forms (631 ms vs. 658 ms). There was no interaction between dominance and presented number ($t < 1$). There was no interaction involving age; thus, the older and younger participants processed these items in the same way.

-*e* plurals.

Overall pattern.

Table 7: The model that best explains overall reaction times to -*e* plurals.

Fixed Factors		β	Standard Error	t-value	p
Intercept		6.6388	0.0476	139.54	< .001
age		-0.1780	0.0361	-4.92	< .001
lemma frequency		-0.0238	0.0073	-3.28	< .01
number		-0.0260	0.0120	-2.16	< .05
dominance : number		-0.0479	0.0172	-2.78	< .01
Random Factors	**Name**	**Variance explained**	**Standard Deviation**	**Correlation**	
noun	intercept	0.00322028	0.056748		
subject	intercept	0.01633216	0.127797		
	dominance	0.00078845	0.028079	-0.860	
Residual		0.03054649	0.174776		

There were 46 items with -*e* plurals. For these items, age had a main effect on reaction times (t = -4.92); younger people showed faster responses than old people (576 ms vs. 690 ms). There was a main effect of lemma frequency, with more frequent words leading to shorter reaction times (β = -0.023836, t = -3.28). Presented number influenced lexical decisions (t = -2.16); responses to singular forms were faster than responses to plural forms (605 ms vs. 637 ms). Dominance interacted with number (t = -2.78). There was an effect of number for singular-dominant nouns (singular: 596 ms, plural: 642 ms, t = 2.36), but not for plural-dominant nouns (singular: 614 ms, plural: 631 ms, t = 1.11). There were no interactions involving the factor age.

-er plurals.

Overall pattern.

Table 10: The model that best explains overall reaction times to *-er* plurals.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.7198	0.0718	93.58	< .001
lemma frequency	-0.0487	0.0119	-4.08	< .001
age	-0.1132	0.0482	-2.35	< .05
age : dominance	-0.0869	0.0438	-1.98	< .05
age : number	-0.1270	0.0433	-2.94	< .01
number : dominance	-0.1058	0.0480	-2.20	< .05
age : number : dominance	0.1392	0.0618	2.25	< .05

Random Factors	Name	Variance explained	Standard Deviation
noun	intercept	0.0009366	0.030604
subject	intercept	0.0130301	0.114149
Residual		0.0250173	0.158169

There were 12 items with *-er* plurals. Age had a main effect on reaction times (t = -2.35); younger people had shorter reaction times than older people (563 ms vs. 685 ms). There was a main effect of lemma frequency; more frequent words led to shorter reaction times (β = -0.04874, t = -4.08). Dominance interacted with number, t = -2.20. There was a significant effect of number for both singular-dominant nouns (singular: 600 ms, plural: 639 ms, t = -2.95) and plural-dominant nouns (singular: 591 ms, plural: 618 ms, t = -2.19), but the latter effect was significantly smaller. Age interacted with dominance; dominance had an effect in the group of older participants (t = 2.97), but not in the younger group (t = 1.53). Age also interacted with number (t = 2.20); presented number had an effect on reaction times for younger participants (t = 4.07), but not for older participants (t = 1.07).

Lastly, there was a three-way interaction between age, dominance, and number ($t = 2.25$). The aforementioned interaction between dominance and number was only present for older participants ($t = -2.26$), but not for younger participants ($t < 1$). Separate analyses for each age group were carried out to explore these interactions.

Younger people.

Table 11: The model that best explains reaction times of younger people to *-er* plurals.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.5779	0.0686	95.95	< .001
lemma frequency	-0.0404	0.0116	-3.49	< .001
number	-0.0788	0.0194	-4.07	< .001

Random Factors	Name	Variance explained	Standard Deviation
noun	intercept	0.0012367	0.035167
subject	intercept	0.0087892	0.093751
Residual		0.0248661	0.157690

For the younger group, there was a main effect of lemma frequency, with more frequent words leading to shorter reaction times ($\beta = -0.04042$, $t = -3.49$). Additionally, number had a main effect of reaction times (singular: 541 ms, plural: 586 ms, $t = -4.07$).

Older people:

Table 12: Factors included in the model that best explains reaction times of older people to *-er* plurals.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.7045	0.0778	86.13	< .001
lemma frequency	-0.0461	0.0129	-3.58	< .001
dominance	0.1193	0.0402	2.97	< .01
number : dominance	-0.1092	0.0484	-2.26	< .05

Random Factors	Name	Variance explained	Standard Deviation	Correlation
noun	intercept	0.00013865	0.011775	
subject	intercept	0.01857792	0.136301	
	number	0.00013865	0.011775	1.000
Residual		0.02512531	0.158510	

For the older group, a more complex pattern was seen: There was a main effect of lemma frequency, with more frequent words leading to shorter reaction times (β = -0.04612, t = -3.58). Dominance had a main effect of reaction times (t = -2.97); reaction to singular-dominant words were slower than reactions to plural-dominant words (697 ms vs. 673 ms). Additionally, dominance interacted with presented number (t = -2.26); there was an effect of number for singular-dominant nouns (singular: 677 ms, plural: 718 ms, t = -1.84) but no effect of number for plural-dominant nouns (singular: 680 ms, plural: 666 ms, t = -1.09).

-*s* plurals.

Overall pattern.

Table 13: The model that best explains overall reaction times to -*s* plurals.

Fixed Factors		β	Standard Error	t-value	p
Intercept		6.6180	0.0533	124.26	< .001
age		-0.1847	0.0489	-3.78	< .001
dominance : number		-0.1436	0.0319	-4.50	< .001
Random Factors	**Name**		**Variance explained**		**Standard Deviation**
noun	intercept		0.0068471		0.082747
subject	intercept		0.0199480		0.141237
Residual			0.0272108		0.164957

There were 13 items with –s plurals. Age had a main effect on reaction times (t = -3.78); younger people had shorter reaction times than older people (516 ms vs. 753 ms). Dominance interacted with presented number, t = -4.5. There was a significant effect of number for singular-dominant nouns (singular: 608 ms, plural: 701 ms, t = 4.05) but no effect of number for plural-dominant nouns (singular: 700 ms, plural: 688 ms, $t < 1$). There was no effect of lemma frequency ($t < 1$). There was no interaction involving age.

With regards to Analysis II (independent factors: lemma frequency, form frequency, dominance, presented number, age), Figures 6 and 7 provide an overview of the reaction times by younger and by older people split by the different plural types tested.

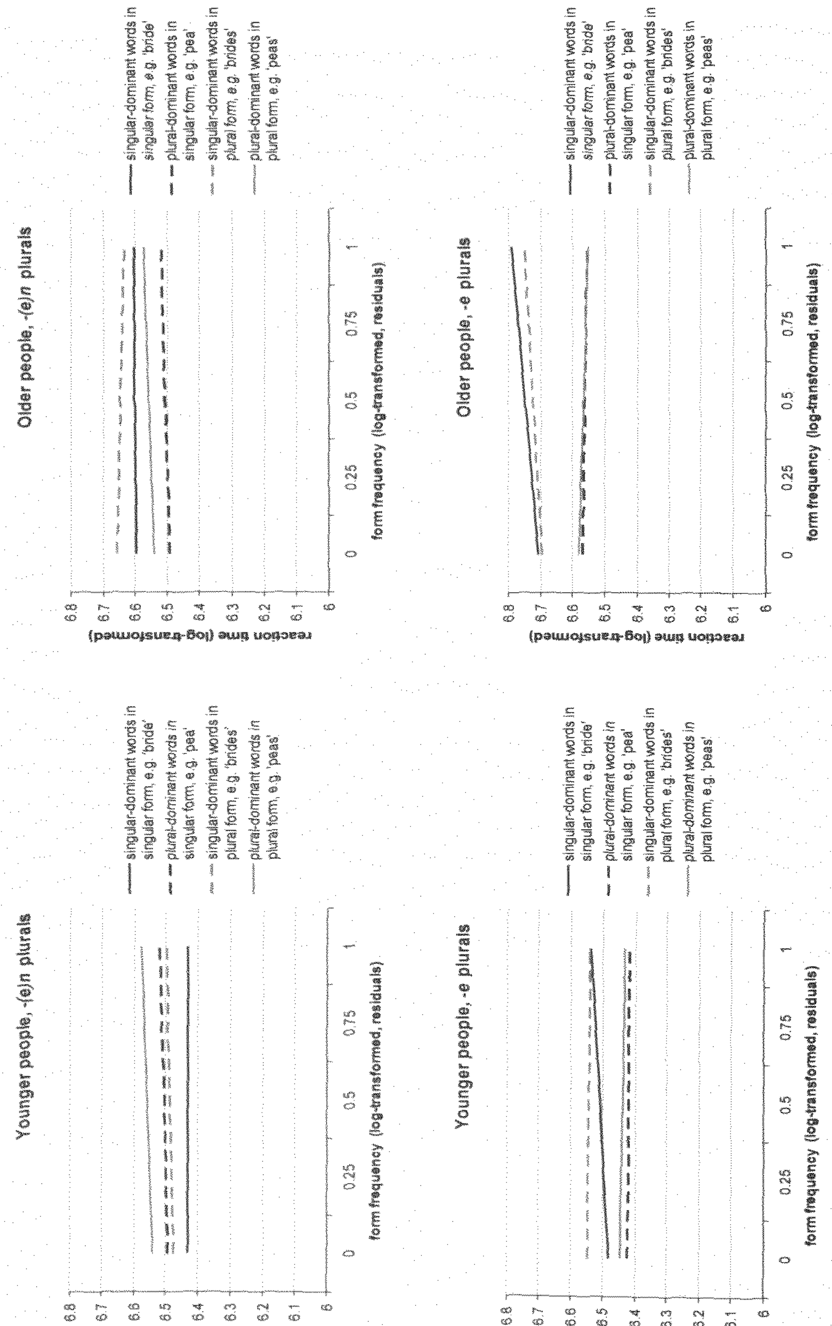


Figure 6: Reaction times as a function of form frequency, dominance, and number.

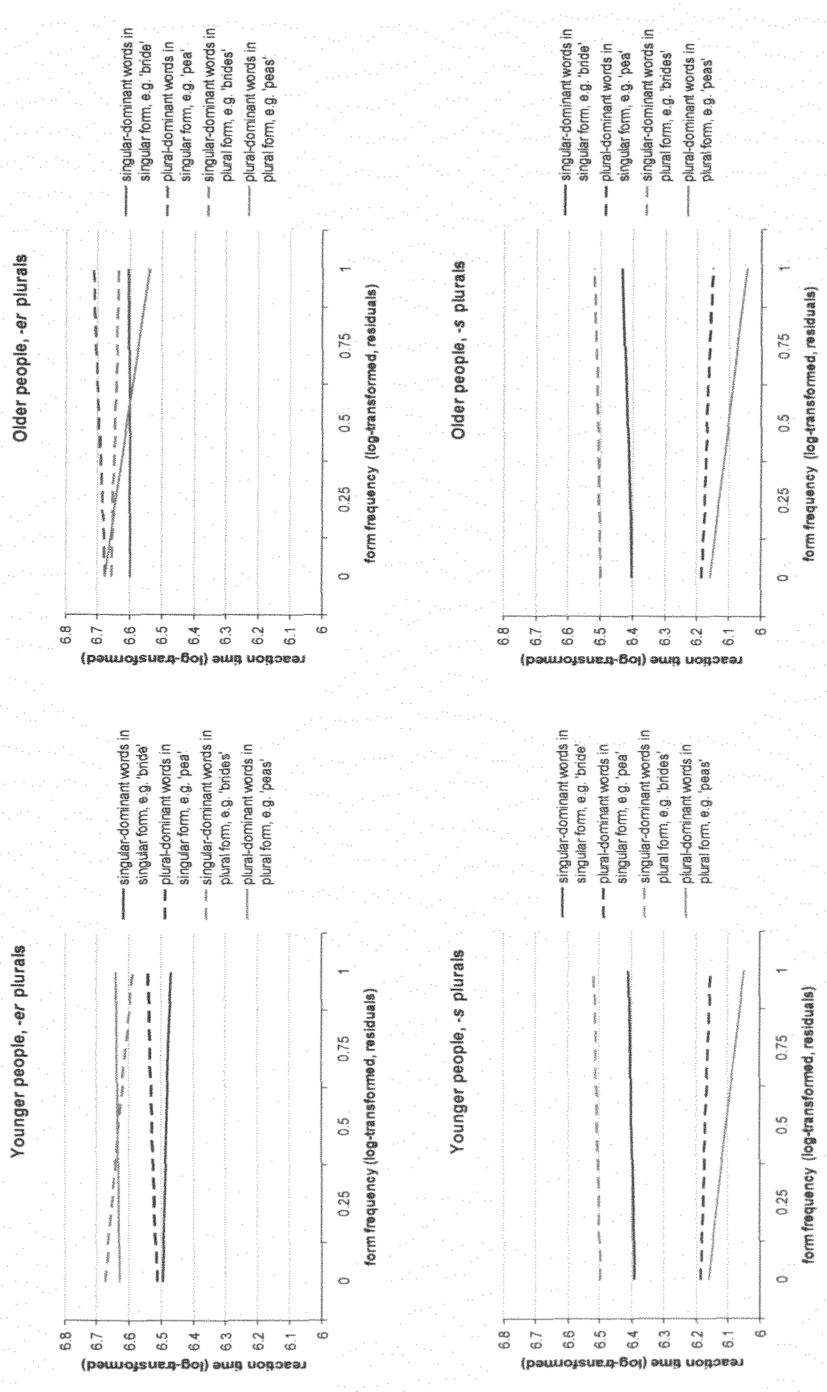


Figure 7: Reaction times as a function of form frequency, dominance, and number.

Analysis II: Effects of form frequency

-(e)n plurals.

Table 16: Factors included in the model that best explains overall reaction times to *-(e)n* plurals.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.6591	0.0370	180.15	< .001
age	-0.1621	0.0423	-3.83	< .001
lemma frequency	-0.0283	0.0040	-7.04	< .001
number	-0.0391	0.0052	-7.46	< .001

Random Factors	Name	Variance explained	Standard Deviation	Correlation	
noun	intercept	0.00665272	0.081564		
	age	0.00259036	0.050896	-0.47	
	number	0.00036941	0.019220	-0.97	0.67
subject	intercept	0.01637500	0.127965		
Residual		0.03014114	0.173612		

For *-(e)n* plurals, the results from Analysis II were identical to Analysis I, as there were no effects of form frequency.

-e plurals.

Overall pattern.

Table 19: The model that best explains overall reaction times to *-e* plurals.

Fixed Factors		β	Standard Error	t-value	p
Intercept		6.6388	0.0476	139.54	< .001
age		-0.1780	0.0361	-4.92	< .001
lemma frequency		-0.0238	0.0073	-3.28	< .01
number		-0.0260	0.0120	-2.16	< .05
dominance : number		-0.0479	0.0172	-2.78	< .01
Random Factors	**Name**	**Variance explained**	**Standard Deviation**	**Correlation**	
noun	intercept	0.00322028	0.056748		
subject	intercept	0.01633216	0.127797		
	dominance	0.00078845	0.028079	-0.860	
Residual		0.03054649	0.174776		

For *-e* plurals, the results from Analysis II were identical to Analysis I, as there were no effects of form frequency.

***-er* plurals.**

Overall pattern.

Table 22: Factors included in the model that best explains overall reaction times to *-er* plurals.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.5329	0.0389	168.14	< .001
form frequency	-0.1094	0.0315	-3.47	< .001
age	-0.1262	0.0458	-2.76	< .01
lemma frequency	-0.1245	0.0305	-4.09	< .001
dominance	0.2363	0.0657	3.60	< .001
form frequency : age	-0.0427	0.0231	-1.85	< .1
dominance : lemma frequency	0.1936	0.0665	2.91	< .01
age : number	-0.0714	0.0314	-2.28	< .05
number : dominance	-0.2834	0.1015	-2.79	< .01

Random Factors	Name	Variance explained	Standard Deviation
noun	intercept	0.00036177	0.01902
subject	intercept	0.01269979	0.11269
Residual		0.02492154	0.15787

Age had a main effect on reaction times (t = -2.76); younger people had shorter reaction times than older people. There were main effects of lemma frequency and of form frequency, with more frequent words leading to shorter reaction times (lemma frequency: β = -0. 12618, t = -4.09; form frequency: β = -0.10938, t = -3.74).

Dominance interacted with number, t = -2.79. There was a significant effect of number for both singular-dominant nouns (t = -3.36) and plural-dominant nouns (t = 2.00), but the latter was significantly smaller.

There was a marginal interaction between age and form frequency (t = -1.85); for older people but not for younger people, there was an effect of form frequency.

Further, age interacted with number; for younger people, but not for older people, there was an effect of presented number (t = -2.28).

Age also interacted with dominance (t = -2.79); dominance had an effect on older people (t = 2.97), but no effect on younger people (t = 1.53). Further, age interacted with number (t = 2.28); presented number had an effect on reaction times for younger people (t = 4.07), but not for older (t = 1.07).

Younger people.

Table 23: The model that best explains reaction times of younger people to *-er* plurals.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.5779	0.0686	95.95	< .001
lemma frequency	-0.0404	0.0116	-3.49	< .001
number	-0.0788	0.0194	-4.07	< .001
Random Factors	**Name**	**Variance explained**	**Standard Deviation**	
noun	intercept	0.0012367	0.035167	
subject	intercept	0.0087892	0.093751	
Residual		0.0248661	0.157690	

For younger people, the results from Analysis II were identical to Analysis I as there was no effect of form frequency (t < 1).

Older people.

Table 24: The model that best explains reaction times of older people to *-er* plurals.

Fixed Factors	β	Standard Error	t-value	p
Intercept	6.5835	0.12801	51.43	< .001
lemma frequency	-0.02684	0.008895	-3.02	< .01
dominance : lemma frequency	0.2077	0.12081	1.72	< .1
number : dominance : form frequency	3.0683	1.51561	2.02	< .05

Random Factors	Name	Variance explained	Standard Deviation	Correlation		
noun	intercept	0.0014417	0.0379569			
subject	intercept	0.0661713	0.2572365			
	dominance	0.0001832	0.0135113	1.00		
	number	0.0000029	0.0016957	1.00	1.00	
	lemma frequency	0.0004220	0.0205441	1.00	1.00	1.00
Residual		0.0224040	0.1496813			

There was a main effect of lemma frequency (β = -0.026836, t = -3.02); high frequency led to faster responses. This effect of lemma frequency interacted with dominance. Higher lemma frequency led to faster reaction times for plural-dominant forms (β = -05143, t = -3.91). However, there was no significant effect of lemma frequency for singular-dominant nouns (β = -0.03572, t = -1.28).

In addition, there was an interaction between presented number, dominance, and form frequency. Post-hoc analyses showed a marginal interaction between form frequency and number for plural-dominant words (t = 1.91), but not for singular-dominant words (t < 1). Form frequency had an influence on the plural forms of plural-dominant words (t = -2.22) but not on singular forms of plural-dominant words or singular-dominant forms (both t < 1).

-*s* plurals.

Table 25: Factors included in the model that best explains overall reaction times to -*s* plurals.

Fixed Factors		β	Standard Error	t-value	p
Intercept		6.6180	0.0533	124.26	< .001
age		-0.1847	0.0489	-3.78	< .001
dominance : number		-0.1436	0.0319	-4.50	< .001
Random Factors	**Name**		**Variance explained**	**Standard Deviation**	
noun	intercept		0.0068471	0.082747	
subject	intercept		0.0199480	0.141237	
Residual			0.0272108	0.164957	

For –*s* plurals, the results from Analysis II were identical to Analysis I, as there were no effects of form frequency.

With regards to lemma frequency, words with -*s* plurals showed a different pattern of lemma frequency compared to the other plural types (t = 2.08), which did not significantly differ from each other (all t < 1). Figure 5 shows the influence of lemma frequency on -*er* plurals, -*(e)n* plurals, and -*e* plurals compared to its influence on -*s* plurals. While lemma frequency facilitated responses to words of the former three plural types (-*er* plurals: β = -0.03822, t = -3.5; -*(e)n* plurals: β = -0.027345, t = -6.68; -*e* plurals: β = -0.023531, t = -3.28), it did not significantly influence reactions to the -*s* plural words (β = 0.01284, t < 1).

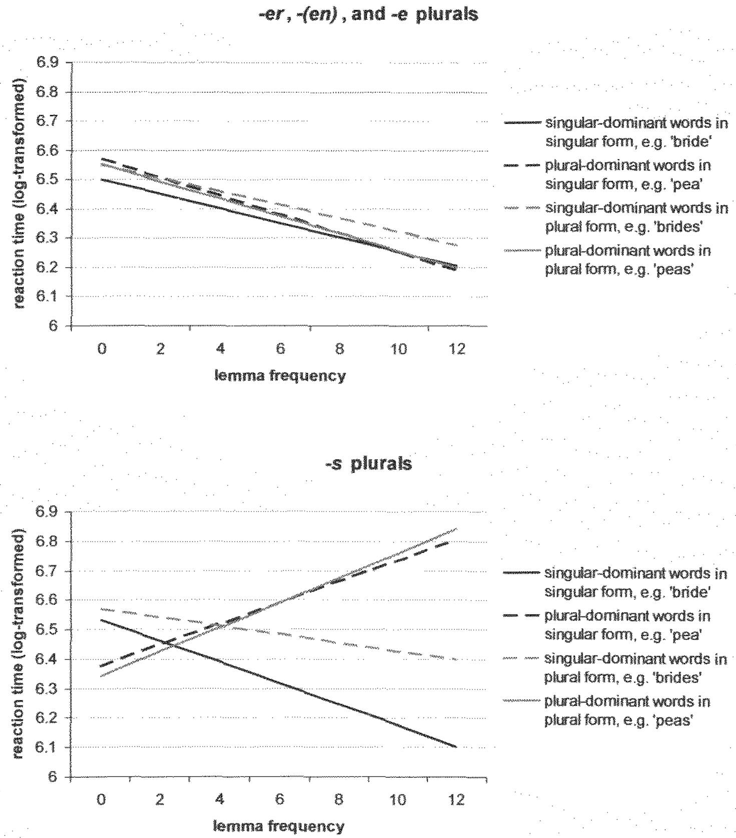


Figure 8: Reaction times across plural types for younger and older people as a factor of lemma frequency, dominance, and presented number. For *-er* plurals, *-(e)*n plurals, and *-e* plurals, there was an effect of lemma frequency for singular and plural forms of singular-dominant and plural-dominant words. For *-s* plurals, there was no significant effect of lemma frequency for any of the four forms.

Discussion

In the present study, we investigated the morphological processing of German noun plurals in younger and older adults. In an earlier, very similar study, we had investigated the processing of such forms in Dutch. The main goal of the present study was to determine whether the results obtained in that study would be replicated, or whether a different pattern might emerge. German is closely related to Dutch but is overall morphologically richer and has a higher number of plural suffixes. As explained in the Introduction, this might lead to differences in the processing of plural forms.

As explained above, we used two ways of analyzing the data. Analysis I follows the original paper by Baayen, Dijkstra et al. (1997). Analysis II investigates form frequency effects as a direct diagnostic of storage. Table 28 gives an overview of the findings.

Table 27: Overview of the results from Analysis I and Analysis II for younger and older participants. Y marks a significant effect, (Y) means a marginal effect.

		-(e)n	*-e*	*-er*	*-s*
Analysis I: Dominance x Presented Number					
Younger	lemma frequency	Y	Y	Y	-
	number	Y	Y	Y	-
	dominance	-	-	-	-
	dominance x number	-	-	-	Y
Older	lemma frequency	Y	Y	Y	-
	number	Y	-	-	-
	dominance	-	-	Y	(Y)
	dominance x number	-	(Y)	Y	Y
Analysis II: Effects of form frequency					
Younger	form frequency	-	-	-	-
	lemma frequency	Y	Y	Y	-
	number	Y	Y	Y	-
	dominance	-	-	-	-
	dominance x number	-	-	-	Y
	dominance x number x form frequency	-	-	-	-
Older	form frequency	-	-	-	-
	lemma frequency	Y	Y	Y	-
	number	Y	-	-	-
	dominance	-	-	-	(Y)
	dominance x number	-	(Y)	-	Y
	dominance x number x form frequency	-	-	Y	-

We will first summarize and discuss the findings for *-e*, *-(e)n, and -er* plurals for younger and for older people. Then, we will turn to *-s* plurals.

Morphological processing in a morphologically rich language

As mentioned earlier, the diagnostics for storage in these analyses are an interaction between dominance and presented number (Analysis I) and an effect of form frequency (Analysis II), see Figure 1.

Across participants and plural types, the results of Analysis I and Analysis II led to similar conclusions. A main effect of number indicates that people decompose singular-dominant and plural-dominant plural forms. Responses to plurals were slower because of the time-consuming parsing processes associated with the decomposition of a morphologically complex word into its constituent morphemes. Importantly, there was no interaction between dominance and number (Analysis I) and no effect of form frequency (Analysis II), which supports the conclusion that the plural forms were computed instead of accessed from storage.

It seems that speakers of German access plural nouns via decomposition rather than from storage. This follows the economy of storage account (Frauenfelder & Schreuder, 1992); a morphologically rich language leads to an increase in storable forms, making whole-word access an inefficient process method. The results are in line with observations from Finnish, where studies have found decomposition of morphologically complex words rather than storage (Bertram et al., 1999; Niemi et al., 1994; Hyönä, Laine, & Niemi, 1995).

In order to be able to compare between Dutch and German, we combined the dataset from Chapter 3 (46 singular-dominant nouns and 43 plural-dominant nouns) with the data for *-(e)n* plurals from the present experiment (70 singular-dominant nouns, 72 plural-dominant nouns). Using the *-(e)n* affix increases comparability as both languages use this plural morpheme.

Table 29: The model that best explains reaction times comparing German and Dutch plurals.

Fixed Factors	β	Standard Error	t-value	
Intercept	6.6461	0.0326	203.72	< .001
dominance	0.0528	0.0148	3.56	< .001
lemma frequency	-0.0273	0.0029	-9.45	< .001
age	-0.1453	0.0260	-5.58	< .001
language : number	-0.0219	0.0109	-2.00	< .05
dominance : number	-0.0548	0.0108	-5.07	< .001
language : number : dominance	0.0285	0.0144	1.97	< .05

Random Factors	Name	Variance explained	Standard Deviation	Correlation
noun	intercept	0.00360652	0.060054	
subject	intercept	0.02032710	0.142573	
	number	0.00025994	0.016123	-1.000
Residual		0.02817598	0.167857	

Lemma frequency acted as a main effect; high-frequency words yielded shorter reaction times than low-frequency items (β = -0.027272, t = -9.45). Age influenced reaction times significantly (t = -5.58), younger people responded faster than older people (594 ms vs. 685 ms). There was a main effect of dominance (t = 3.56); plural-dominant nouns led to faster responses than singular-dominant nouns (631 ms vs. 639 ms). Language interacted with presented number (t = -2.00); the main effect of number was stronger for the German nouns (t = -7.19) than for the Dutch nouns (t = -4.80). Dominance interacted with number; the effect of number was stronger for singular-dominant words (t = -11.02) than it was plural-dominant words (t = -3.20).

Importantly, there was a three-way interaction between language, dominance, and number. The interaction between number and dominance was only present for the Dutch data (t = -5.59), but not for the German data (t = -1.11). Form frequency did not significantly influence reaction times (t = -1.35)

Evidently, there are differences in the way German speakers and Dutch speakers process plural nouns. Dutch speakers showed an interaction between dominance and presented number, indicating a dual-route process, in which singular-dominant plural forms are decomposed and plural-dominant plural forms are accessed from storage. German speakers, on the other hand, displayed a main effect of presented number but no interaction between dominance and number. This suggests that they decompose all plural forms into their constituent morphemes.

One explanation for this is the high number of possible forms that needs to be stored in a morphologically rich language like German. Assuming that the storage-based route needs to look up the full form, it will be slower as a function of the number of possible inflected forms stored in the mental lexicon. This makes the decompositional route the faster mechanism due to the high number of possible forms stored in the mental lexicon.

Further, it is conceivable that the decompositional route is faster for speakers of a morphologically rich language (compared to speakers of a language with simple morphology) due to their experience with the computational processes at work. However, when we compared the time cost of decomposition of singular-dominant words between the Dutch speakers and the German speakers from (*-(e)n* plurals only), the difference between responses to the monomorphemic singular forms (*bride*) and the polymorphemic plural forms (*brides*) were almost identical between the two languages (German: 35 ms, Dutch: 37 ms). Thus, it seems unlikely that German speakers decompose these plural forms because they are faster at decomposing complex words.

The role of age in morphological processing

Turning to the role of age in morphological processing, we find an influence of age for both types of analyses. Older people were slower to respond to all target items, which is not surprising given the age-related decline of processing speed (Salthouse, 1985; 1996). Further, older people showed different response patterns compared to younger people for some of the plural types we tested.

Interpreting Analysis I, we found an interaction between dominance and presented number for *-er* plurals, *-e* plurals, and *-s* plurals for older people, but not for younger people. For all of these plural types, there was an effect of number for singular-dominant words, but not for plural-dominant words, indicating that the former are accessed via decomposition and the latter from the storage. Turning to Analysis II of the data of the older people, for *-er* plurals, we found indeed an effect of form frequency for the plural forms of plural-dominant words (*peas*), suggesting that these forms are accessed from the storage. However, there was no significant effect of form frequency for *-e* plural words or *-s* plural words. This indicates that despite the interaction between dominance and presented number in the first analysis, older people do not access *-e* plurals or -s plurals from the storage but instead decompose them.

Taking the analyses together, it seems that older people process nouns in a very similar way compared to younger people, through parsing. Our analyses suggest, however, that older people access plural-dominant *-er* plurals from storage, as they showed form-frequency effects for these forms. This may be surprising at first glance, given that *-er* plurals make up the smallest group of plurals with only 2%-8% of all plurals using this affix. Why would older people store these forms?

A first possible reason lies in differences between the lemma frequencies of the four plural types we tested. Although consisting of a relatively small group, *-er* plural words have a high type frequency, containing words such as *Kinder* 'children', *Eier* 'eggs', or *Bilder* 'images'. In our experiment, items with *-er* plurals have a higher lemma frequency than the other items. In previous chapters, we argued that older people access morphologically complex verbs from storage due to the accumulated exposure over the course of their lifetime. It is possible that the high lemma frequency of *-er* plural words is responsible for their storage-based access by the older participants.

Second, as mentioned in the introduction, psycholinguistic research has established a number of linguistic factors that influence whether a morphologically complex word is decomposed or stored. Bertram et al. (1999) and Bertram et al. (2000) investigated the role of affixal productivity and homonymy in Dutch and Finnish. Productivity means the ease with which an affix can be attached to a word to create a new word. Homonymy is equivalent to confusability; an affix is homonymic if it serves several functions. The authors found that morphologically complex words with unambiguous, productive affixes yielded faster reaction times than morphologically simplex counterparts. Words with an ambiguous or unproductive affix yielded similar reaction times as monomorphemic words (when form frequency, lemma frequency, and length were controlled for). It seems that ambiguity as well as an absence of productivity makes a word more likely to be accessed as a full form from the mental lexicon. Where does *-er* fall with regards to homonymy and productivity?

Besides being a plural morpheme, *-er* is a derivation marker, turning verb stems (*malen* → *Maler*, 'to paint' → 'painter') and adjectives (*nett* → *Netter*, 'nice' →

'nice one') into nouns. It is the comparative affix for adjectives (*nett* → *netter*, 'nice' → 'nicer') and is used to inflect adjectives for case and gender (*ein netter Mann*, 'a $\text{nice}_{\text{NOMMASCINDEF}}$ man'). It becomes obvious that *-er* is highly ambiguous, serving several morphological functions for different lexical categories. At the same time, *-er* is very unproductive as a plural marker. As mentioned earlier, the group of *-er* plural words is very small and new words usually take *-(e)n* or *-s* but not *-er* as their plural affix (Köpcke, 1988). Given its high degree of homonymy and lack of productivity, it is not surprising that *-er* plural words are more likely to be processed in a similar way to monomorphemic words, that is, via the storage route. The affixes *-s* and *-(e)n*, on the other hand, are very productive and have few other grammatical function (*-s*: genitive marker, *-(e)n*: infinitive marker. This might explain why *-er* plurals show signs of storage in older people, while the other affixes do not.

Note, however, that the evidence for storage of plural-dominant *-er* plurals was only present for older people. It is important to consider that the above mentioned factors lemma frequency, homonymy, and productivity, do not necessitate storage of morphologically complex forms but contribute to it.

It needs to be stressed that the findings related to age are to be interpreted with caution. As it was difficult to recruit older participants, our sample size was rather small. Further, these people comprise a less homogeneous group than the younger participants, all of whom were Psychology undergraduate students. In addition, our experiment included only 12 *-er* plural items.[13]

[13] The distribution of plural types mirrors the token frequencies of the different plural types in the language. Item selection was constrained by matching lemma frequencies between singular and plural types and the exclusion of plural doublets (e.g. *Wort* 'word' has both *Worte* and *Wörter* as its plural) and homophones (e.g. *Spiele*, 'games' and $\text{'play}_{\text{1STSINGPRES}}\text{'}$).

The special status of the -s affix

Words with *-s* plurals show a pattern that is different from that of the other plural types. For all participants, presented number influenced responses to singular-dominant words (*bride* < *brides*), but not responses to plural-dominant words (*pea* = *peas*). Baayen and colleagues (Baayen, Dijkstra et al., 1997, Baayen et al., 2003) interpreted an interaction between dominance and number as an indicator for a dual-route access (decomposition of singular-dominant words and storage of plural-dominant words). It is noteworthy, however, that in their studies, there was no difference between responses to singular forms (*bride* = *pea*), but instead a difference in reactions to plural forms (*peas* < *brides*). Studies on English plurals (New et al., 2004; Sereno & Jongman, 1997; Biedermann, Beyersmann, Mason, & Nickels, 2013) similarly observe an interaction between dominance and presented number for English plurals. Both studies found a significant difference between responses to singular-dominant words only. However, the responses to plural forms are "elevated" as they are in our study. See Figure 6 for a comparison between our findings, the findings by Baayen, Dijkstra et al. (1997), and the findings by New et al. (2004).

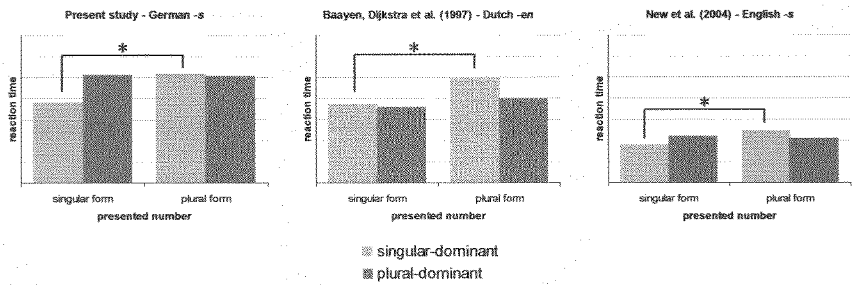


Figure 9: Comparison between the –s plural words in our study, the results by Baayen, Dijkstra et al. (1997), and the results by New et al. (2004). While all three studies found an interaction between dominance and number (due to an effect of number for singular-dominant forms but no such effect for plural-dominant forms), there are differences with regards to the reaction times for the plural-dominant forms compared to singular-dominant forms.

The interaction between dominance and number suggests that plural-dominant plural forms of *-s* plural words are stored, while their singular-dominant counterparts are decomposed. This finding would go against predictions that *-s* is the regular plural affix (Clahsen et al., 1992; Clahsen et al., 1993; Marcus et al., 1993; Clahsen, 1999; Weyerts et al., 1997). However, turning to Analysis II, we did not find a significant form-frequency effect for plural forms of plural-dominant words for the *–s* plural affix, which would be indicative of storage.

Looking at the items that make up our set of *-s* plural words, it becomes evident that several of them are unusual. Of the 26 original items, 10 are loanwords (*Bonbon*, *Detail*, *Gag*, *Genre*, *Mokka*, *Pascha*, *Snob*, *Song*, *Trick*, *Yard*), an additional 6 are abbreviations or colloquialisms (*Ami*, *Dia*, *Opa*, *Papa*, *Vati*, *Zoo*). Importantly, this is not an artifact of our dataset but instead reflects the tendency for loanwords to take on *-s* as their plural affix. Half of the items were excluded from the analyses due to less than 50% acceptance by our participants, despite the fact that *-s* plural items were on average as frequent as *-(e)n* plural words (*-s*: 3.40, *-(e)n*: 3.57).

It seems that the set of *-s* plural words is special. A very small set (2%-8% of German words) to begin with, it consists of many "special" (if not infrequent) words, due to the tendencies for loanwords, proper names, acronyms, clippings, and other unusual forms to take on this affix. Importantly, the *-s* plural affix does not seem to be special with regards to morphological processing. Proponents of the view that *-s* is the regular plural affix while the other plural types are irregular would have predicted storage of *-er* plurals, *-(e)n* plurals, and *-e* plurals. Instead, we found that younger people decompose all of these plural forms.

This paper addressed two factors influencing the processing of morphologically complex forms: morphological richness and age. First, we found evidence that speakers of German, a morphologically rich language, decompose noun plurals and do not generally access them as full forms from the mental lexicon. These results tie in with studies on Finnish that find a prevalence of decomposition of morphologically complex forms. Our findings are in contrast to research on languages like Dutch, French, Italian, or Spanish – for these morphologically less rich languages, researchers found evidence for access of complex words from storage.

A possible explanation is that a morphologically complex language has exponentially more inflected forms than a less rich language: accessing fully inflected forms from storage is a very inefficient and time-consuming process if there are a great number of forms.

Importantly, these findings do not rule out the existence of a dual-route system. It is conceivable that upon reading/hearing a word, both routes are activated and the storage route is simply too slow to find a suitable candidate (due to the increased size of the lexicon), before the decomposition route leads to a lexical decision.

Further, we would like to stress that our findings only provide evidence for the comprehension of morphologically complex words. Baayen, Schreuder, de Jong, and Krott (2002) mention modality (comprehension vs. production) as an important factor for the balance between storage and comprehension. Learners of German have few difficulties identifying and understanding a plural form, while they tend to struggle with the correct plural formation in production. This is not surprising; as mentioned earlier, in German, it is largely arbitrary to which plural paradigm a given word belongs. Thus, it is possible that during production, German plural forms are not computed by combining stem and affix, but instead, the speaker follows an associative link between stored representations.

Second, we investigated the role of age. By and large, older speakers processed noun plurals in a similar manner to younger speakers, via decomposition. The only exception is *-er* plurals, for which we found evidence suggesting that older people access plural-dominant plural forms (*peas*) from storage.

Appendix

Table A1: List of all target items.

Items		Frequency (log-transformed) Lemma	Form SG	Form PL	Dominance	Gloss	Average RT SG	Average RT PL	Average Accuracy SG	Average Accuracy PL
-(e)n plurals										
Achse	Achsen	4.06	3.81	2.56	singular	axis	603	681	0.95	1.00
Amsel	Amseln	1.95	1.79	0.00	singular	blackbird	655	680	1.00	1.00
Bluse	Blusen	3.64	3.30	2.40	singular	blouse	579	624	0.95	1.00
Bude	Buden	3.18	2.71	2.20	singular	den	575	550	0.86	0.35
Diät	Diäten	3.53	3.18	2.30	singular	diet	725	673	1.00	0.95
Distel*	Disteln	3.22	2.89	1.95	singular	thistle	---	---	0.49	1.00
Elite	Eliten	3.47	3.40	0.69	singular	elite	567	559	0.95	0.82
Esche*	Eschen	2.08	1.79	0.69	singular	ash (tree)	---	---	0.68	0.47
Etappe	Etappen	5.20	4.96	3.66	singular	leg (of journey)	653	652	0.91	0.90
Eule	Eulen	2.20	1.95	0.69	singular	owl	609	642	1.00	0.82
Fabel	Fabeln	3.37	3.22	1.39	singular	fable	617	645	0.95	1.00
Fähre	Fähren	3.04	2.77	1.61	singular	ferry	625	648	0.95	0.95
Figur	Figuren	5.54	5.18	4.36	singular	figure	633	702	1.00	1.00
Fläche	Flächen	5.21	4.85	4.01	singular	surface	594	639	1.00	0.86
Flagge	Flaggen	4.33	4.01	3.04	singular	flag	595	644	0.90	0.95
Flanke	Flanken	3.40	2.89	2.48	singular	flank	596	756	0.75	0.73
Flinte	Flinten	1.39	1.10	0.00	singular	shotgun	692	735	0.85	0.73
Formel	Formeln	4.96	4.62	3.74	singular	formula	599	660	0.95	1.00
Gasse	Gassen	3.78	3.22	2.94	singular	lane	668	714	0.86	0.86
Gerte	Gerten	1.10	0.69	0.00	singular	whip	689	859	0.90	0.62
Glosse*	Glossen	2.77	2.48	1.39	singular	gloss	---	---	0.59	0.50
Hälfte	Hälften	6.25	6.23	2.30	singular	half	598	702	1.00	0.90
Haube	Hauben	2.77	2.56	1.10	singular	cap	671	740	0.95	0.82
Hemd	Hemden	5.01	4.62	3.74	singular	shirt	561	625	0.95	1.00
Henne	Hennen	3.58	3.14	2.56	singular	hen	745	790	0.91	0.86
Hülse	Hülsen	2.56	2.08	1.61	singular	pod	603	638	0.86	1.00
Hymne	Hymnen	3.37	2.77	2.56	singular	hymn	770	763	0.91	0.81
Kabine	Kabinen	4.34	4.22	2.20	singular	cabin	605	606	0.86	0.95
Kapuze	Kapuzen	2.08	1.79	0.69	singular	hood (textile)	666	712	0.95	0.86
Kehle	Kehlen	4.04	3.83	2.40	singular	throat	608	858	0.71	0.62
Kelle*	Kellen	2.94	2.83	0.69	singular	ladle	---	---	0.77	0.37
Krippe*	Krippen	2.30	2.20	0.00	singular	crib	---	---	0.81	0.48
Krume*	Krumen	1.61	1.39	0.00	singular	crumb	---	---	0.27	0.33
Kuppe*	Kuppen	2.56	2.08	1.61	singular	knoll	---	---	0.65	0.45
Kutte*	Kutten	1.95	1.39	1.10	singular	habit (textile)	---	---	0.59	0.43
Lampe	Lampen	3.69	3.69	2.83	singular	lamp	522	579	0.95	0.95
Lanze	Lanzen	3.37	3.18	1.61	singular	lance	607	717	0.90	0.77
Laune	Launen	4.19	4.01	2.40	singular	mood	664	661	0.91	0.71
Lunge	Lungen	3.71	3.18	2.83	singular	lung	620	583	0.95	1.00
Lupe	Lupen	3.50	3.47	0.00	singular	magnifying glass	659	798	0.90	0.77
Mähne	Mähnen	1.95	1.79	0.00	singular	mane	636	709	0.90	0.86
Mappe	Mappen	3.61	3.37	2.08	singular	folder	684	768	0.95	0.86
Masche	Maschen	2.08	1.79	0.69	singular	mesh	655	669	0.91	0.86
Meute*	Meuten	3.09	3.04	0.00	singular	crowd	---	---	0.90	0.00
Motte	Motten	1.10	0.69	0.00	singular	moth	634	625	1.00	0.90
Mulde	Mulden	3.09	3.04	0.00	singular	cavity	510	588	0.55	0.67

* Excluded due to low accuracy.

Items		Frequency (log-transformed)			Dominance	Gloss	Average RT		Average Accuracy	
		Lemma	Form							
			SG	PL			SG	PL	SG	PL
Mütze	Mützen	4.14	3.91	2.56	singular	cap	642	649	1.00	0.95
Narr	Narren	3.47	2.89	2.64	singular	jester	583	610	0.86	0.90
Note	Noten	5.62	5.17	4.61	singular	note	601	600	1.00	1.00
Oase	Oasen	2.30	1.79	1.39	singular	oasis	702	854	0.86	0.75
Oper	Opern	5.59	5.48	3.33	singular	opera	673	591	0.95	1.00
Panne	Pannen	3.89	3.40	2.94	singular	breakdown	625	567	0.86	0.86
Parade	Paraden	3.37	3.09	1.95	singular	parade	613	618	1.00	0.81
Pause	Pausen	5.55	5.40	3.58	singular	break	607	535	1.00	0.90
Pfanne	Pfannen	2.64	2.40	1.10	singular	pan	609	591	1.00	0.90
Pille	Pillen	4.23	4.04	2.48	singular	pill	560	608	0.95	0.91
Rampe	Rampen	3.37	3.22	1.39	singular	ramp	627	707	1.00	0.82
Robe*	Roben	1.95	1.61	0.69	singular	vestment	---	---	0.86	0.51
Rune*	Runen	1.39	1.10	0.00	singular	rune	---	---	0.36	0.43
Rute*	Ruten	1.95	1.79	0.00	singular	rod	---	---	0.73	0.47
Serie	Serien	5.23	5.08	3.26	singular	series	634	654	0.95	1.00
Sichel	Sicheln	2.40	2.30	0.00	singular	sickle	729	793	0.82	0.85
Sippe*	Sippen	2.89	2.64	1.39	singular	tribe	---	---	0.59	0.43
Sonate*	Sonaten	2.48	2.20	1.10	singular	sonata	---	---	0.48	0.71
Sonde*	Sonden	3.33	3.00	2.08	singular	sonde	---	---	0.67	0.50
Stange	Stangen	3.97	3.37	3.18	singular	pole	649	665	0.95	1.00
Stube	Stuben	4.56	4.41	2.64	singular	parlor	689	702	0.82	0.81
Stute*	Stuten	4.17	3.95	2.56	singular	mare	---	---	0.90	0.49
Suppe	Suppen	3.99	3.78	2.30	singular	soup	580	575	0.95	0.81
Taille*	Taillen	2.08	1.95	0.00	singular	taille	---	---	0.86	0.45
Tante	Tanten	5.28	5.22	2.40	singular	aunt	531	556	0.90	1.00
Tasse	Tassen	4.11	3.76	2.89	singular	cup	579	590	0.95	0.95
Tatze	Tatzen	1.10	0.69	0.00	singular	paw	654	680	0.82	0.76
Tenne	Tennen	2.56	2.48	0.00	singular	barn floor	---	---	0.48	0.27
Theke	Theken	3.85	3.83	0.00	singular	counter	684	686	0.91	0.90
Tinte	Tinten	2.56	2.48	0.00	singular	ink	706	702	0.77	0.76
Torte	Torten	2.64	2.56	0.00	singular	tart	599	626	0.95	0.95
Treppe	Treppen	5.12	4.91	3.47	singular	stairs	668	691	0.95	0.90
Tube	Tuben	2.83	2.64	1.10	singular	tube	---	---	0.57	0.47
Vase	Vasen	3.53	3.26	2.08	singular	vase	539	626	0.95	0.91
Wade	Waden	2.64	2.20	1.61	singular	calf	712	757	0.68	0.70
Wanne	Wannen	3.37	3.33	0.00	singular	tub	598	640	1.00	0.91
Warze	Warzen	1.39	1.10	0.00	singular	wart	614	628	0.95	0.95
Wonne	Wonnen	2.30	2.20	0.00	singular	bliss	645	717	0.90	0.86
Zange	Zangen	2.89	2.40	1.95	singular	tongs	609	588	0.95	1.00
Zeche	Zechen	4.29	3.76	3.40	singular	mine	677	833	0.77	0.76
Zeit	Zeiten	8.73	8.65	6.22	singular	time	538	648	1.00	0.90
Zelle	Zellen	5.04	4.49	4.19	singular	cell	586	646	0.95	0.90
Zunge	Zungen	4.55	4.45	2.20	singular	tongue	562	606	1.00	1.00
Agent	Agenten	4.70	3.43	4.37	plural	agent	643	699	0.95	0.90
Aktie	Aktien	6.22	4.65	5.98	plural	stock (finan.)	681	674	0.90	1.00
Arie	Arien	2.20	0.69	1.95	plural	aria	695	826	0.95	0.82
Asket	Asketen	2.56	0.69	2.40	plural	ascetic	781	711	0.76	0.82
Aster	Astern	2.08	1.10	1.61	plural	aster	674	659	0.86	0.68
Auge	Augen	7.50	5.80	7.29	plural	eye	552	541	1.00	1.00
Auster	Austern	1.61	0.69	1.10	plural	oyster	650	668	1.00	1.00
Blume	Blumen	5.25	3.00	5.14	plural	flower	507	520	1.00	1.00
Bohne	Bohnen	3.50	0.00	3.47	plural	bean	651	548	0.91	0.86
Borke*	Borken	1.79	0.69	1.39	plural	bark (tree)	---	---	0.42	0.68
Dame	Damen	6.70	5.77	6.20	plural	lady	541	660	1.00	0.95

Items		Frequency (log-transformed)			Dominance	Gloss	Average RT		Average Accuracy	
		Lemma	Form							
			SG	PL			SG	PL	SG	PL
Düne	Dünen	2.83	1.61	2.48	plural	dune	645	679	0.68	0.86
Echse	Echsen	2.64	0.69	2.48	plural	lizard	696	772	0.82	0.81
Ente	Enten	4.83	3.61	4.48	plural	duck	715	724	0.95	0.81
Erle	Erlen	1.79	0.69	1.39	plural	alder	645	679	0.80	0.73
Falke	Falken	3.58	2.20	3.30	plural	falcon	555	555	1.00	0.90
Faser	Fasern	3.74	1.95	3.56	plural	fibre	676	703	0.95	0.95
Felge	Felgen	2.40	1.10	2.08	plural	felly	734	674	0.77	0.95
Ferse	Fersen	2.40	1.39	1.95	plural	heel	624	747	0.86	0.86
Fink	Finken	2.20	1.10	1.79	plural	finch	606	744	0.86	0.82
Furie*	Furien	1.10	0.00	0.69	plural	fury	---	---	0.47	0.60
Galle*	Gallen	3.58	2.20	3.30	plural	gall	---	---	1.00	0.48
Ganove	Ganoven	1.10	0.00	0.69	plural	hoodlum	688	724	1.00	0.91
Gatte	Gatten	3.53	2.71	2.94	plural	spouse	624	681	0.80	0.76
Geisel	Geiseln	3.78	2.71	3.37	plural	hostage	595	698	1.00	0.95
Gräte	Gräten	1.61	0.69	1.10	plural	fishbone	910	787	0.77	0.90
Halde*	Halden	3.30	2.30	2.83	plural	heap	---	---	0.55	0.33
Held	Helden	5.56	4.65	5.04	plural	hero	609	621	0.95	1.00
Hüfte	Hüften	3.71	2.83	3.18	plural	hip	643	678	1.00	0.90
Hürde	Hürden	4.25	2.77	3.99	plural	obstacle	641	681	0.95	0.91
Ion*	Ionen	3.04	2.20	2.48	plural	ion	---	---	0.24	0.38
Kanone	Kanonen	3.40	2.08	3.09	plural	canon	632	670	1.00	1.00
Karte	Karten	5.65	4.74	5.13	plural	card	585	669	0.95	0.77
Kerze	Kerzen	4.11	3.00	3.71	plural	candle	552	595	0.95	1.00
Kladde*	Kladden	6.56	0.00	0.69	plural	daybook	---	---	0.73	0.48
Klippe	Klippen	3.30	1.61	3.09	plural	cliff	704	657	1.00	0.95
Komet	Kometen	3.00	2.08	2.48	plural	comet	---	---	0.50	0.76
Krabbe	Krabben	2.40	0.69	2.20	plural	crab	701	718	1.00	0.95
Kröte	Kröten	1.95	1.10	1.39	plural	toad	553	635	0.90	0.91
Kufe	Kufen	1.10	0.00	0.69	plural	blade (sport)	---	---	0.43	0.36
Lagune	Lagunen	1.95	0.69	1.61	plural	lagoon	767	753	0.86	0.81
Lakai*	Lakaien	3.04	1.61	2.77	plural	lackey	---	---	0.48	0.77
Larve	Larven	2.08	1.10	1.61	plural	larva	659	696	0.90	0.95
Lende	Lenden	1.61	0.69	1.10	plural	loin	791	651	0.86	0.81
Lore*	Loren	2.20	1.10	1.79	plural	mine cart	---	---	0.32	0.10
Löwe	Löwen	5.53	4.19	5.22	plural	lion	510	588	1.00	0.95
Made	Maden	2.40	1.39	1.95	plural	maggot	717	707	0.71	0.73
Mandel	Mandeln	2.56	0.69	2.40	plural	almond	605	560	1.00	1.00
Meise	Meisen	1.39	0.00	1.10	plural	tit (bird)	652	664	1.00	0.95
Minute	Minuten	7.26	5.96	6.95	plural	minute	565	566	1.00	1.00
Möwe	Möwen	3.76	2.56	3.40	plural	seagull	635	611	0.73	0.95
Mumie	Mumien	1.79	0.69	1.39	plural	mummy	668	747	0.86	0.86
Name	Namen	7.41	6.01	7.10	plural	name	596	615	0.95	0.81
Narbe	Narben	3.93	2.89	3.50	plural	scar	615	651	0.95	1.00
Nelke	Nelken	3.18	1.79	2.89	plural	clove	588	664	0.90	0.95
Niere	Nieren	3.47	2.48	3.00	plural	kidney	568	653	0.95	0.95
Nonne	Nonnen	4.32	3.04	3.99	plural	nun	698	673	0.95	1.00
Ochse	Ochsen	3.40	2.08	3.09	plural	ox	572	632	0.95	0.90
Olive	Oliven	2.30	0.69	2.08	plural	olive	652	608	0.95	1.00
Öse*	Ösen	1.95	0.69	1.61	plural	eye (needle)	---	---	0.62	0.40
Pappel*	Pappeln	2.77	1.10	2.56	plural	poplar	---	---	0.76	0.46
Pfote	Pfoten	2.08	0.00	1.95	plural	paw	605	713	0.86	0.76
Planke*	Planken	1.10	0.00	0.69	plural	plank	---	---	0.57	0.45
Poet	Poeten	2.64	1.39	2.30	plural	poet	785	660	0.73	0.86
Prämie	Prämien	4.90	3.85	4.47	plural	bonus	622	675	0.95	0.86

Items		Frequency (log-transformed) Lemma	Form SG	Form PL	Dominance	Gloss	Average RT SG	Average RT PL	Average Accuracy SG	Average Accuracy PL
Psalm	Psalmen	1.61	0.00	1.10	plural	psalm	648	722	0.71	0.90
Rabe	Raben	2.71	1.10	2.48	plural	raven	716	665	0.82	0.90
Ratte	Ratten	3.71	1.79	3.56	plural	rat	589	537	0.95	1.00
Rebe	Reben	2.40	0.69	2.20	plural	vine	---	---	0.71	0.43
Rippe	Rippen	3.26	1.95	2.94	plural	rib	594	580	0.86	1.00
Rivale	Rivalen	3.74	2.20	3.50	plural	rival	618	640	0.95	0.95
Rosine	Rosinen	2.20	1.39	1.61	plural	raisin	615	574	0.91	1.00
Rube*	Ruben	3.74	2.08	3.53	plural	beet	---	---	0.46	0.90
Rusche	Rüschen	1.39	0.00	1.10	plural	ruffle	728	813	0.71	0.82
Sirene	Sirenen	3.71	2.89	3.14	plural	siren	668	659	1.00	0.91
Sorte	Sorten	4.88	3.95	4.38	plural	sort	673	692	1.00	0.86
Spatz	Spatzen	3.22	1.61	3.00	plural	sparrow	575	649	0.95	1.00
Stulle*	Stullen	1.10	0.00	0.69	plural	sandwich	---	---	0.76	0.44
Tapete	Tapeten	3.30	2.20	2.89	plural	wallpaper	661	581	0.95	1.00
Tonne	Tonnen	6.10	4.20	5.93	plural	ton	595	596	1.00	1.00
Traube	Trauben	2.94	1.61	2.64	plural	grape	584	629	1.00	1.00
Waffe	Waffen	6.18	4.96	5.83	plural	weapon	579	634	1.00	1.00
Wange	Wangen	4.52	3.58	4.03	plural	cheek	564	635	0.95	1.00
Wanze	Wanzen	1.61	0.00	1.39	plural	bug	591	609	0.95	0.86
Wespe	Wespen	2.56	1.10	2.30	plural	wasp	603	670	0.95	0.95
Wimper	Wimpern	3.04	1.39	2.83	plural	eyelash	678	652	0.95	0.86
Wolke	Wolken	4.91	3.33	4.67	plural	cloud	594	570	1.00	1.00
Zeder*	Zedern	1.10	0.00	0.69	plural	cedar	---	---	0.81	0.50
Ziege	Ziegen	3.89	2.89	3.43	plural	goat	593	723	1.00	0.95
-e plurals										
Abend	Abende	6.67	6.51	3.83	singular	evening	484	659	1.00	0.82
Bier	Biere	5.61	5.57	1.95	singular	beer	506	573	1.00	1.00
Eid*	Eide	3.43	3.04	1.95	singular	oath	---	---	0.95	0.33
Gast	Gäste	6.38	5.67	4.68	singular	guest	587	543	0.95	1.00
Halm	Halme	2.83	2.30	1.95	singular	stalk	641	669	0.80	0.68
Hals	Hälse	5.56	5.41	1.95	singular	neck	549	620	1.00	0.81
Heim*	Heime	4.55	4.19	1.95	singular	home	---	---	0.95	0.47
Hengst	Hengste	3.64	3.43	1.61	singular	stallion	554	680	1.00	0.76
Hering	Heringe	3.76	3.30	2.64	singular	herring	603	769	0.90	0.86
Hof	Höfe	6.16	5.88	3.47	singular	court	626	682	0.77	0.76
Kern	Kerne	5.25	5.06	3.33	singular	core	603	590	1.00	0.86
Korb	Körbe	4.86	4.75	2.08	singular	basket	639	607	0.82	0.86
Mehl*	Mehle	3.26	3.18	0.69	singular	flour	---	---	0.90	0.41
Moment	Momente	5.45	5.32	3.00	singular	moment	630	680	0.95	1.00
Moor	Moore	3.33	2.77	2.40	singular	swamp	687	692	0.86	0.76
Nacht	Nächte	6.86	6.80	3.78	singular	night	606	549	1.00	1.00
Ozean	Ozeane	4.34	3.78	1.61	singular	ocean	659	671	0.95	0.95
Saft	Säfte	3.43	3.30	1.10	singular	juice	549	622	1.00	1.00
Schnur	Schnüre	3.09	2.83	0.69	singular	string	725	740	0.71	0.68
Stein	Steine	5.89	5.26	4.70	singular	stone	517	531	1.00	1.00
Storch	Störche	3.47	3.09	2.20	singular	stork	569	652	1.00	1.00
Strand*	Strände	4.98	4.88	1.10	singular	beach	---	---	0.95	0.50
Stuhl	Stühle	5.43	5.02	3.78	singular	chair	579	627	1.00	0.95
Symbol	Symbole	4.80	4.39	3.37	singular	symbol	595	630	0.86	1.00
System	Systeme	6.64	6.19	4.29	singular	system	668	668	0.95	0.90
Zwerg	Zwerge	2.77	2.40	1.61	singular	dwarf	609	592	0.91	1.00
Atom	Atome	4.72	3.04	4.03	plural	atom	599	657	0.86	1.00
Darm	Därme	2.89	1.79	2.20	plural	intestines	587	747	0.95	0.86
Frosch	Frösche	3.18	1.61	2.64	plural	frog	600	556	1.00	0.95

Items		Frequency (log-transformed)			Dominance	Gloss	Average RT		Average Accuracy	
		Lemma	Form							
			SG	PL			SG	PL	SG	PL
Frucht	Früchte	4.98	3.61	4.45	plural	fruit	621	576	0.86	1.00
Hai	Haie	6.79	5.64	6.14	plural	shark	591	729	0.91	0.95
Hormon	Hormone	2.77	0.69	2.20	plural	hormone	613	677	1.00	0.91
Huf*	Hufe	3.40	1.10	2.94	plural	hoof	---	---	0.43	1.00
Impuls	Impulse	4.83	3.40	4.37	plural	impulse	634	694	1.00	0.95
Kniff*	Kniffe	2.20	1.10	1.39	plural	trick	---	---	0.59	0.76
Kredit	Kredite	5.28	3.47	4.91	plural	loan	602	643	1.00	1.00
Laus	Läuse	2.56	0.69	1.95	plural	louse	627	618	0.90	1.00
Lohn	Löhne	5.69	4.74	5.04	plural	salary	641	611	0.95	0.90
Molch*	Molche	2.56	1.10	1.79	plural	newt	---	---	0.50	0.62
Monat	Monate	7.58	6.08	6.50	plural	month	582	573	1.00	1.00
Mönch	Mönche	5.00	3.93	4.23	plural	monk	662	573	0.82	0.95
Organ	Organe	5.80	4.72	4.97	plural	organ	604	679	1.00	0.91
Pedal	Pedale	3.09	1.39	2.48	plural	pedal	672	676	1.00	1.00
Pilz	Pilze	3.40	1.10	3.14	plural	mushroom	612	665	1.00	1.00
Plakat	Plakate	4.70	3.26	4.03	plural	poster	591	748	0.95	0.91
Schaf	Schafe	4.42	2.40	3.99	plural	sheep	630	675	0.73	0.80
Schuh	Schuhe	5.27	3.43	4.87	plural	shoe	584	542	0.95	1.00
Span*	Späne	1.79	0.69	1.39	plural	chip (wood)	---	---	0.19	0.82
Tarif	Tarife	4.33	3.18	3.78	plural	tariff	660	730	0.91	0.95
Vers	Verse	5.12	3.74	4.25	plural	verse	656	623	0.90	0.82
Zahn	Zähne	5.29	2.48	4.84	plural	tooth	548	524	1.00	1.00
Zopf	Zöpfe	3.74	2.77	3.00	plural	braid (hair)	592	623	1.00	0.95
Zweig	Zweige	4.77	3.22	3.78	plural	twig	636	633	0.95	0.95
-er plurals										
Amt	Ämter	6.55	6.18	3.85	singular	office	566	550	1.00	1.00
Dach	Dächer	5.32	4.98	3.30	singular	roof	599	639	0.95	0.86
Dorf	Dörfer	6.34	5.76	4.22	singular	village	590	680	0.95	0.95
Feld	Felder	6.39	5.84	4.51	singular	field	602	676	0.86	0.86
Nest	Nester	3.87	3.58	2.20	singular	nest	643	755	0.76	0.76
Wald	Wälder	6.17	5.71	4.03	singular	forest	608	591	0.95	1.00
Brett	Bretter	4.20	3.00	3.33	plural	board	588	688	0.95	0.73
Ei	Eier	5.66	4.01	5.00	plural	egg	586	626	1.00	1.00
Huhn	Hühner	4.39	2.64	3.95	plural	chicken	624	582	0.91	1.00
Kalb	Kälber	3.76	2.56	2.94	plural	calf (animal)	629	665	1.00	0.95
Kind	Kinder	7.83	6.70	7.14	plural	child	510	521	1.00	1.00
Rind	Rinder	4.58	1.79	4.20	plural	cattle	625	640	0.95	1.00
-s plurals										
Kamera	Kamera	4.98	4.87	2.71	singular	camera	606	688	1.00	1.00
Kino	Kino	5.01	4.75	3.53	singular	cinema	581	773	0.95	0.85
Menü	Menü	2.40	2.20	0.69	singular	menu	617	775	0.95	0.76
Mokka*	Mokka	3.04	3.00	0.00	singular	mocha	---	---	0.71	0.45
Moped*	Moped	2.77	2.20	1.95	singular	scooter	---	---	0.68	0.50
Motel*	Motel	2.08	1.79	0.69	singular	motel	---	---	0.68	0.43
Opa	Opa	4.06	3.78	2.64	singular	grandfather	608	728	0.95	0.82
Papa	Papa	4.41	4.25	2.48	singular	dad	542	735	1.00	1.00
Pascha*	Pascha	2.83	2.77	0.00	singular	pasha	---	---	0.59	0.43
Trick	Trick	4.33	3.93	3.22	singular	trick	627	559	0.95	1.00
Tabu	Tabu	3.56	3.00	2.71	singular	taboo	694	692	0.86	0.81
Vati*	Vati	2.89	2.83	0.00	singular	dad	---	---	0.82	0.21
Zoo*	Zoo	4.51	4.32	2.77	singular	zoo	---	---	1.00	0.36
Ami	Ami	2.20	0.69	1.95	plural	American (abbr.)	---	---	0.18	0.29
Bonbon	Bonbon	3.43	2.48	2.94	plural	candy	640	638	0.90	1.00
Detail	Detail	4.62	3.66	4.13	plural	detail	630	575	1.00	0.95

Items		Frequency (log-transformed)			Dominance	Gloss	Average RT		Average Accuracy	
		Lemma	Form							
			SG	PL			SG	PL	SG	PL
Dia	Dia	2.64	1.39	2.30	plural	slide	701	656	0.76	0.82
Gag*	Gag	2.40	1.10	2.08	plural	gag	---	---	0.50	0.25
Genre*	Genre	3.14	1.95	2.77	plural	genre	---	---	0.90	0.50
Hindu*	Hindu	1.10	0.00	0.69	plural	Hindu	---	---	0.25	0.30
Silo*	Silo	1.61	0.00	1.39	plural	silo	---	---	0.75	0.42
Snob*	Snob	2.20	1.10	1.79	plural	snob	---	---	0.29	0.36
Song	Song	2.71	1.79	2.20	plural	song	721	754	0.76	0.64
Sowjet	Sowjet	5.67	3.66	5.53	plural	Soviet	875	858	0.76	0.81
Yard*	Yard	4.03	3.18	3.47	plural	yard	---	---	0.56	0.41
Zebra	Zebra	4.96	3.93	4.51	plural	zebra	691	698	0.95	0.86

Summary and Conclusions

Chapter 6

Most written or spoken utterances are a sequence of smaller parts. While words and their meanings and relations between them are at the center of interest for most speakers, many linguists are concerned with even smaller units of language. It is easy to see that *antidisestablishmentarianism* consists of several parts, but few people realize that this is also true for the word *inflected*. The prefix *-in* and the suffix *-ed* are morphemes affixed to the stem *flect*. As one of the smallest linguistic units, morphemes can change the meaning of a word as well as its grammatical function. In the case of *inflected*, both *in-* and *-ed* are morphemes contributing to the meaning of the whole word. There has been much debate about whether words consisting of several morphemes – so-called morphologically complex or polymorphemic words - are stored and processed as whole words or whether they are always composed (during production) and decomposed (during comprehension) anew.

Models of morphological processing fall into one of two categories, single-mechanism models or dual-mechanism models. Single-mechanism models assume that all morphologically complex forms are processed in a similar way. They differ, however, with regards to how this single mechanism works. While full-decomposition (or full-parsing) models postulate that all complex forms are obligatorily decomposed into their constituent morphemes, full-listing models claim that even derived and inflected forms are accessed as full forms without the involvement of computations. A third group, connectionist models, simulate human behavior through computational models; these models "learn" a language through associations between a "heard" input and an "expected" output and are able to account for key findings of psycholinguistic research.

In contrast to single-mechanism models, dual-route models assume that both decomposition and whole-word access are active during word processing. Dual-route models come in a variety of flavors. The earliest models by Pinker (e.g. words-and-rules theory by Pinker and Prince, 1994) made a strict distinction between regular and irregular morphology. While regular inflections such as *walked* are computed using a rule, irregular inflections like *made* are looked up as full forms from the mental lexicon. Other variants, such as the parallel dual-route race model (Schreuder & Baayen, 1995) propose that for morphologically complex forms, both routes are activated at the same time and the one that is faster at finding an appropriate lexical entry is the one to lead to a lexical decision.

Which of the two routes in the parallel dual-route race model is faster depends on a number of factors. One of them is word frequency. How often a word occurs in the language influences the speed with which it is recognized during comprehension (Chumbley & Balota, 1984; Whaley, 1978; Monsell, 1991) and how long it takes to name it during production (Oldfield & Wingfield, 1965; Balota & Chumbley, 1985; Forster & Chambers, 1973). Interestingly, word-form frequency (i.e., the frequency of a specific form such as *made* or *walked*) only influences reaction times for irregular forms but not for regular forms (Bybee & Slobin, 1982; Prasada, Pinker, & Snyder, 1990), which is taken as evidence in favor of dual-route models: regular forms are computed, irregular forms are stored as full forms. However, it has been shown that above a certain frequency threshold, even regular verb forms are processed as whole words despite their morphological complexity (Alegre & Gordon, 1999; Lehtonen & Laine, 2003; Soveri, Lehtonen, & Laine, 2007). A word's frequency seems to influence not only how fast it is accessed from the mental lexicon, but also in what way it is accessed.

Besides properties of the stem, past research has shown that properties of the affix, such as productivity and homonymy, are also of importance (Bertram, Laine, & Karvinen, 1999; Bertram, Schreuder, & Baayen, 2000). If an affix is unambiguous (i.e., it serves only one meaning) and productive (i.e., it is readily used for new words), the likelihood for decomposition of morphologically complex words is high. If, on the other hand, an affix is ambiguous or not very productive, stem-affix combinations are more likely to be accessed as whole words.

There are mixed findings with regards to semantic transparency. While some researchers found that semantically opaque words (e.g. *casual* – *casualty*) are not decomposed but are processed like monomorphemic forms with a form overlap (Feldman & Soltano, 1999), others find no difference between opaque and transparent words (Roelofs & Baayen, 2002; Lüttmann, Zwitserlood, & Bölte, 2011). There is evidence suggesting that individual differences can explain these differences: Andrews and Lo (2013) carried out a priming experiment and tested the participants' spelling and vocabulary scores. The participants with a high vocabulary score compared to their spelling score showed stronger priming for morphologically transparent word pairs compared to opaque word pairs. Participants whose spelling score exceeded their vocabulary score showed no differences in priming for transparent and opaque words. The authors argue that the relative difference between vocabulary score and spelling score is an index of sensitivity to semantic vs. orthographic properties of words. People with a "semantic profile" consider the semantics of a morphologically complex word, leading to stronger priming for transparent word pairs as only these are truly semantically related; people with an "orthographic profile" focus more on the form of a morphologically complex word, leading to priming for opaque word pairs as well due to their form overlap. This highlights the importance of including individual differences in psycholinguistic research.

Past research has focused on establishing linguistic factors influencing whether or not a word is accessed through decomposition. My thesis addresses the influence of cognitive factors, such as working memory, age, and task demands. Further, I studied linguistic factors: lexical category and the morphological richness of a language.

Chapter 2 investigated the influence of working memory and age on the processing of regular and irregular past-tense forms in Dutch. The working-memory system is responsible for maintaining and manipulating information. One of the main arguments against morphological decomposition is that keeping several morphemes in working memory leads to increased processing load, making decomposition an unlikely strategy (Butterworth, 1983). I manipulated working memory load through a dual-task in which participants had to remember a 2- or a 5-digit number while performing a lexical decision task. If working memory serves the decompositional process, a high working memory load is expected to slow down responses to morphologically complex forms but not to simple forms.

I tested people of a wide age range (18-84 years) to address the role of exposure. Due to the flexible organization of the mental lexicon, factors such as word frequency influence how fast and in what way words are processed. Research has shown that regular words of a high frequency are accessed as full forms from the storage rather than decomposed into their constituents (Alegre & Gordon, 1999; Lehtonen & Laine, 2003; Soveri, Lehtonen, & Laine, 2007; Stemberger & MacWhinney, 1986). On a participant level, this could mean that older people are more likely to process regular inflections as full forms than younger people, given that they had more exposure to fully inflected forms over the course of their life.

An auditory and a visual lexical decision experiment yielded very similar results. Age influenced the reaction time pattern for regular compared to irregular past-tense verbs. Young people showed an interaction between form frequency and regularity; while reaction times to irregular forms were subject to a form-frequency effect, there was no evidence of such a frequency effect for regular forms. A form-frequency effect is usually taken as evidence for storage of a form in the mental lexicon. This indicates that young people store irregular past-tense forms but decompose regular past-tense forms. Replicating a number of studies (Bybee & Slobin, 1982; Marcus, Brinkmann, Clahsen, Wiese, & Pinker, 1995; Prasada et al., 1990; Ullman, 1993; Seidenberg & Bruck, 1990), this finding is in line with predictions made by dual-route models.

Older people, on the other hand, showed no interaction between regularity and form frequency. Instead, there was an effect of form frequency for both regular and irregular past-tense inflections. This indicates that older people do not decompose regular inflected verbs into their constituent morphemes, but instead retrieve complete stored forms for all verb inflections.

There was no effect of working memory load. While people made more errors when they had to remember a five-digit number than a two-digit number, the high load did not slow down responses in the lexical decision task. This could mean that working memory is not part of the processes associated with morphological decomposition. However, it is possible that cognitive load is more crucial for morphological processing at a higher stage of the comprehension process, as decomposition is a highly automatized process and happens very early during recognition (Rastle & Davis, 2008).

The findings from Chapter 2 led to the question whether decomposition of regular inflections is still an option for older participants. Could older people be encouraged to decompose regular inflected past-tense forms? In Chapter 3, I used the same target words as in Chapter 2, but manipulated the pseudowords. Previous work (LaBerge, 1971) indicated that the nature of distractors can influence depth of processing. "Difficult" pseudowords have been shown to lead to deeper phonological, morphological and semantic processing (James, 1975; Waters & Seidenberg, 1985; Taft, 2004). Older participants might be encouraged to decompose morphologically complex words into their constituent morphemes if presented with "difficult" pseudowords that appear to be morphologically complex, such as overregularized forms like **denkte* (*'think-ed'). This was contrasted with a version of the same experiment using "easy" pseudowords which were largely identical to the ones used in Chapter 2.

I expected the nature of the pseudowords to influence the reaction time pattern for older people; when presented with difficult pseudowords, older people were expected to decompose regular inflected verbs, while easy pseudowords were expected to lead to whole-word access as in Chapter 2. For younger participants, I did not expect any differences between the easy- and difficult-pseudoword conditions.

The experiment showed an interaction between pseudoword type, regularity, and form frequency for younger people, but not for older people. The younger participants displayed an interaction between form frequency and regularity only when the pseudowords were difficult. When pseudowords were easy, there was a main effect of form frequency for regular as well as irregular forms. This indicates that young people decomposed morphologically complex forms only when the task was difficult. The reaction time pattern of older people was not influenced by the nature of the pseudowords. Instead, they displayed a form-frequency effect for all verbs in both conditions, indicating a whole-word access of all forms.

Having found evidence for a whole-word access in older people, I then examined whether this effect would generalize from past-tense verbs to other inflected forms. In Chapter 4, I investigated the phenomenon of number dominance in plural nouns. While the majority of nouns have a singular form that is more frequent than their plural form (e.g. *bride* vs. *brides*), there are numerous examples of plural-dominant nouns with a plural form that is more frequent than its singular counterpart (e.g. *peas* vs. *pea*). Previous work on Dutch (Baayen, Dijkstra, & Schreuder, 1997; Baayen, McQueen, Dijkstra, & Schreuder, 2003), Italian (Baayen, Burani, & Schreuder, 1997), Spanish (Dominguez, Cuetos, & Segui, 1999), and French (New, Brysbaert, Segui, Ferrand, & Rastle, 2004) supported parallel dual-route race models of morphological processing. While the plural forms of singular-dominant words are accessed via decomposition, plural forms of plural-dominant words are accessed as full forms due to their high frequency. Chapter 4 adds to the existing literature on plural processing in two ways. First, the aforementioned studies exclusively used young participants. My experiment included an older sample. Second, in the past, authors have usually analyzed experiments on number dominance by determining the presence or absence of an interaction between dominance and presented number (i.e., whether the participants hear or see the singular or the plural form of a given noun). In addition to this traditional analysis, I investigated the influence of form frequency as a continuous factor on reaction times.

In the first analysis, I found an interaction between dominance and number; while there was an effect of number for singular-dominant words (reactions to *bride* were faster than reactions to *brides*), there was such no effect for plural-dominant words (*pea* = *peas*). Turning to the analysis of form frequency, I found an interaction between form frequency, dominance, and number. There was an effect of form frequency for plural forms of plural-dominant words (*peas*), but not for any of the other forms. Both of these analyses favor a dual-route race model which predicts that morphologically complex forms will be accessed as full forms if their frequency is high enough (*peas*), whereas low-frequency forms (*brides*) are decomposed into their constituent morphemes.

Importantly, older participants showed the same pattern as younger participants, indicating that they process plurals in a similar manner. 48 of the 50 people in this experiment also participated in Experiment 1 of Chapter 3; so the same older people who accessed past-tense verb forms as full forms, decomposed plural nouns into stem and affix.

Chapter 5 addressed the processing of noun plurals in German. German is morphologically richer than Dutch. It has five different plural affixes (*-Ø, -er, -(e)n,*

-e, and *-s*) and it is largely arbitrary to which paradigm a given noun belongs. The experiment was very similar to the one in Chapter 4 but instead of just one plural affix, I included stimuli from four of the five plural paradigms. With regards to the influence of morphological richness on how plural nouns are accessed – via the storage route or via decomposition –, arguments can be made for either direction. On the one hand, the arbitrariness of which word uses which plural might lead to a stronger reliance on storage. Otherwise, the mental lexicon would need to store which plural rule is applied for which stem. On the other hand, storing possible inflections in the mental lexicon seems very uneconomic. For morphologically rich languages, the reliance on full-listing would mean searching through a mental lexicon which is time-consuming and inefficient.

The results show that the majority of German noun plurals are indeed accessed in a different manner compared to Dutch noun plurals. The younger people showed a main effect of presented number for words with *-er* plurals, *-(e)n* plurals, and *-e* plurals. This indicates that they decompose these plural forms rather than store them. Older people show a similar pattern for *-(e)n* plurals, and *-e* plurals. I did, however, find an interaction between dominance and presented number for the older people's responses to words with *-er* plural. This interaction indicates that older people use decomposition to access the plural forms of singular-dominant nouns (e.g., *brides*) but they access the plural forms of plural-dominant nouns (e.g., *peas*) as full forms from their mental lexicon. This conclusion is corroborated by an effect of form frequency for the plural forms of plural-dominant nouns.

The morphological richness of a language seems to influence morphological processing. In a language with different inflectional paradigms, readers (and probably also listeners) are more likely to use decomposition instead of whole-word access.

The age differences, however, showed that the way we process morphologically complex words is not fixed but malleable. Looking at the properties of the affix that led to storage-access in older people, there are differences between *–er* plurals on the one hand, and *–e* plurals and *–(e)n* plurals on the other hand. Words with –er plurals are of higher lemma frequency than the other nouns, which might make the full forms more likely to be stored. Further, the *–er* affix is very ambiguous (it serves several inflectional and derivational purposes) and not very productive (new words usually take -(e)n or -s as their plural affix) – both of these factors have been shown to promote whole-word storage of morphologically complex words (Bertram, Laine, & Karvinen, 1999; Bertram, Schreuder, & Baayen, 2000).

Cognitive and linguistic factors influencing morphological processing

As mentioned earlier, while dual-route models are able to explain the majority of key findings in morphological research, their flexibility and omnipotence has been criticized. In order to make falsifiable predictions, dual-route models need to include factors that influence whether a morphologically complex word is accessed as a full form or via decomposition. Figure 1 illustrates the factors studied in this dissertation.

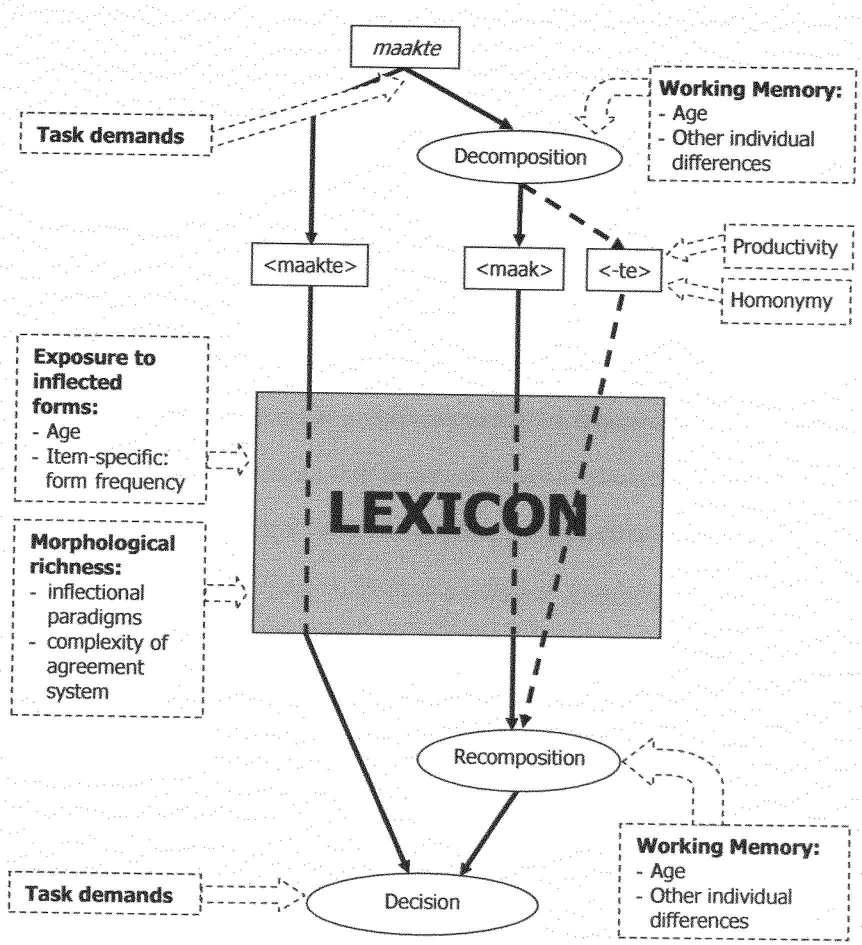


Figure 1: A dual-route model of inflectional processing. Dashed boxes indicate factors that influence the relative speed of the two routes.

Exposure to inflected forms

There is evidence that previous exposure changes the structural organization of the mental lexicon, leading to regular forms being easier to recognize as full forms. Regular words of high frequency are accessed from the storage rather than through parsing (Alegre & Gordon, 1999; Lehtonen & Laine, 2003; Soveri, Lehtonen, & Laine, 2007; Lehtonen, Niska, Wande, Niemi, & Laine, 2006). It is conceivable that exposure also works on a subject basis. Through encounters with regular inflected forms over the course of their life time, older people might be faster at recognizing these forms as whole words. Younger people, on the other hand, may not have accumulated enough encounters with an inflected form to access it as a whole word before the decomposition route finds a suitable entry. One way to test this theory further is through a training study. In my experiments, participants saw every word form only once. Instead, one could use exposure as a predictor for reaction times and show target items several times. Repeated exposure is expected to lead to whole-word access for morphologically complex items over time where it is absent at the beginning of the experiment.

Working Memory

Another possible explanation for the age differences in morphological processing between younger and older people is the difference in working memory capacities, which decline with age (Dobbs & Rule, 1989; Salthouse, 1991; Salthouse & Babcock, 1991). It is conceivable that the computational processes that are necessary to decompose and recombine a morphologically complex word are slowed down to a point at which whole-word access is faster for older people. A working-memory task targeting the very early decomposition process (Rastle & Davis, 2008) might be powerful enough to tax the decomposition process in younger people, leading to whole-word access for morphologically complex forms. Additionally, future work involving more direct measures of working memory (such as operational span) could help find more conclusive evidence.

Task demands

In Chapter 3, younger participants decomposed regular inflected verbs, when the task was made difficult through confusing pseudowords such as overregularizations (e.g. *thinked*). However, there is evidence for whole-word access of the same target words by the same participants when pseudowords were easy to spot (e.g. *plits*). Interestingly, the easy pseudowords used in Chapter 3 are largely identical to the pseudowords used in Chapter 2, where we found that young people decompose regular verbs in a dual-task situation in which they had to remember digit strings at the same time. It seems that the general demands of the task influence how words are processed. The decompositional route appears like a safer alternative that is used when the processing system is faced with a difficult situation. Further, task demands may come into play during the final phase of the lexical decision.

Lexical category

While older people accessed all morphologically complex past-tense verbs as full forms, they decomposed singular-dominant plural nouns into their constituent morphemes. It seems that there are differences between verbs and nouns that lead them to be processed in a different manner. After ruling out differences in frequency and concreteness, the exact reasons why nouns are more prone to decomposition in older people compared to verbs remains unclear. However, the study adds to the bulk of research finding developmental (Nelson, 1973; Benedict, 1979), behavioral (Shao, Roelofs, & Meyer, 2012), and neurological (Perani et al., 1999; Dehaene, 1995; Preissl, Pulvermüller, Lutzenberger, & Birbaumer, 1995; Pulvermüller, Lutzenberger, & Preissl, 1999) differences between verb and noun processing.

Morphological richness

When processing complex forms of a morphologically rich language, people seem more likely to decompose these forms than to access them from storage. Access of fully inflected forms from storage seems like a very uneconomic way of processing in a language that has a multitude of different forms for every content word (Frauenfelder & Schreuder, 1992). Morphological richness has a number of processing consequences. An important question for further research is whether it is the number of different inflectional paradigms (e.g. different types of plural affixes) that affects the likelihood of decomposition or whether is the amount of grammatical categories that a given word gets inflected for (e.g. number, tense, aspect, mood) and their levels (e.g. number of cases).

Limitations

Age as the basis of other differences

All experiments reported here compare the performance of a younger student sample to people over the age of 60. As age by itself is not a factor directly affecting word processing, I tried to explain the changes in performance by differences in exposure to inflected words between younger and older people as well as age-related changes in processing. While I was able to replicate the age differences in past-tense processing with different samples of older people, the exact causes of this difference are unclear and my explanations remain speculative. Future research is necessary to understand why younger and older people differ in the way they process complex forms. Larger samples from the "normal" population can help disentangling factors that might be confounded with age. Age-related differences in working memory, general processing speed, IQ, educational background might contribute to differences in lexical processes.

Lexical Decisions

It is important to note that all of the findings reported in this thesis are based on lexical-decision experiments. While this is a widely used experimental paradigm, one needs to consider what exactly is measured in lexical-decision tasks and their shortcomings. To what extent reflect lexical decisions actual differences in lexical processing?

Lexical-decision tasks differ from listening and reading in the real world. Devoid of semantic and syntactic context, lexical decisions draw on metalinguistic knowledge and concentrate on the form of a stimulus, rather than its meaning. In addition to lexical access, a decision component contributes to reaction times. Studies comparing lexical decision to word naming and eye fixations during sentence reading found that lexical decisions lead to inflated frequency effects (Schilling, Rayner, & Chumbley, 1998; Juhasz, Starr, Inhoff, & Placke, 2003). One reason is that a highly frequent word speeds up not only the lexical-access part of a lexical decision, but also the decision part through familiarity with the stimulus. For naming and sentence reading, processes such as articulation and text integration dampen the frequency effect. Can we still rely on lexical decisions to give us reliable insight into word processing?

The answer seems to be yes. While finding differences in the size of its effect, Schilling et al. (1998) and Juhasz et al. (2003) reported significant effects of frequency on reaction times and eye fixations. Further, even if the effects of familiarity lead to an overestimation of the contribution of frequency, these effects must originate in a frequency difference in the mental lexicon.

Additionally, one might argue that the different reaction time patterns found for younger people compared to older people are a reflection of differences in the decision component of lexical decisions, rather than differences in lexical access. Arguably, the main effect of age (older people show slower responses than younger people) can be explained by differences in the decision process (including but not limited to differences in general processing speed, criterion setting, motor execution). However, these differences in the decision process cannot explain the different effects of age for verbs compared to nouns (Chapter 3 vs. Chapter 4) and for different languages (Chapter 5). Instead, these different patterns presumably have their origin in differences in the way that younger and older people store and retrieve morphologically complex words.

Differences across languages

The majority of experimental psycholinguistic research focuses on the comprehension and production of Indo-European languages. With the notable exception of Finnish, most studies on morphological processing concentrate on Germanic languages (especially English, German, and Dutch) and a few Romance languages.

One needs to be careful when generalizing findings from this subset of related languages to other languages. Chapter 5 describes morphological richness of a language as an important factor influencing morphological processing. Besides the number of morphological paradigms and grammatical categories, there are many more differences between the morphological systems of different languages.

Languages differ in how they combine word stems with affixes and their morpheme-per-word ratio. Agglutinative languages (e.g. Turkish, Basque, Korean) allow for the combination of a virtually infinite number of distinct morphemes. The Turkish word *uygarlaştıramayabileceklerimizdenmişsinizcesine* contains 12 morphemes and means roughly '(behaving) as if you were one of those whom we might not be able to civilize' (Oflazer & Güzey, 1994). Fusional languages (e.g. Sanskrit, Greek, Russian) overlay and merge different morphemes to denote several grammatical categories in one morpheme. For example, in Latin, *bonum* means *good*, with *-um* denoting gender, case, and number at the same time. Isolating languages (e.g. Thai, Chinese, Vietnamese) have a low morpheme-per-word ratio with very little morphology and a large number of free morphemes. Arguably, these different morphological systems are expected to lead to differences in mental representations and in morphological processing. It is conceivable that agglutinative languages involve more decomposition due to the high number of possible forms, while isolating languages access the few morphologically complex words that exist from storage. Importantly, the flexibility of the dual-route model allows for language-specific differences in how morphologically complex words are accessed.

Conclusion

The research in this thesis provides insights into the factors influencing morphological processing. Do people process morphologically complex such as *walked* or *brides* as whole words or are they decomposed? Evidently, the mental lexicon as well as the processes involved in the comprehension of morphologically complex words are malleable and influenced by the speaker, the situation, the properties of the word, and the language.

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Nederlandse samenvatting

De meeste geschreven of gesproken uitingen zijn een reeks van kleinere eenheden. Waar de meeste sprekers met name geïnteresseerd zijn in de woorden en hun betekenis en de relatie daartussen, houden veel taalwetenschappers zich bezig met nog kleinere eenheden van taal. Het is makkelijk te zien dat een woord zoals *arbeidsongeschiktheidsverzekering* samengesteld is uit verschillende delen, maar weinig mensen realiseren zich dat dit ook geldt voor het woord *vervoeging*. Het voorvoegsel *ver-* en het achtervoegsel *-ing* zijn morfemen die aan de woordstam *voeg* worden toegevoegd. Morfemen zijn de kleinste betekenisdragende eenheden en kunnen zo zowel de betekenis als de grammaticale rol van een woord veranderen. In het voorbeeld *vervoeging* dragen zowel *ver-* en *-ing* bij aan de betekenis van het gehele woord. Er is veel onenigheid over de vraag of woorden bestaande uit meerdere morfemen zoals *gloeide* en *erwten*, worden opgeslagen en verwerkt als één geheel, of dat ze steeds opnieuw worden samengesteld uit de losse morfemen.

Zogenoemde 'dual-route' modellen gaan ervan uit dat zowel ontleding van de morfemen als toegang tot het gehele woord actieve processen zijn tijdens woordverwerking. Sommige van deze modellen stellen dat voor morfologisch complexe woorden zoals *gloeide* beide routes tegelijkertijd worden geactiveerd en dat het proces dat als eerste een geschikt lemma vindt, de winnaar is. de lexicale beslissing (of het een bestaand woord is of niet) zal worden geleid door het snelste proces. Welke van de twee routes het snelste zal zijn, hangt af van verschillende factoren. Eén van deze factoren is woordfrequentie. Voor een woord dat is opgeslagen in het mentale lexicon (een soort woordenboek in de hersenen), zal de tijd waarin dit woord wordt herkend of geproduceerd afhangen van hoe vaak dit woord voorkomt in de taal.

Deze dissertatie onderzoekt welke andere factoren een rol spelen bij het begrijpen van vervoegde werkwoorden en verbogen zelfstandige naamwoorden. Een belangrijk resultaat is het verschil in het verwerken van regelmatig vervoegde werkwoorden tussen jong volwassenen en ouderen (Hoofdstuk 2 en 3). Hoewel jongeren woorden zoals *gloeide* ontleden in *gloei* en *-de*, verwerken ouderen het woord als geheel. Er zijn verschillende verklaringen mogelijk, bijvoorbeeld ervaring met vervoegde vormen en verschillen in werkgeheugen.

Ervaring met vervoegde vormen

Er zijn aanwijzingen dat eerdere ervaring de organisatiestructuur van het mentale lexicon kan aanpassen. Ouderen zijn in hun leven veelvuldig in aanraking gekomen met vervoegde vormen; dit kan er wellicht toe leiden dat ze sneller zijn geworden in het herkennen van een woord in zijn geheel. Daartegenover zijn jongeren mogelijk nog niet vaak genoeg een vervoegde vorm tegengekomen waardoor de toegang tot het gehele woord langzamer is dan het ontleden van het woord om zo het item in het mentale lexicon te vinden.

Werkgeheugen

Het verschil in werkgeheugen, dat met oplopende leeftijd achteruit gaat, zou een andere verklaring voor de gevonden leeftijdsverschillen in de verwerking van vervoegde vormen kunnen zijn. De computationele processes die nodig zijn voor het ontleden en recombineren van morfologisch complexe woorden zouden zodanig vertraagd kunnen zijn dat toegang tot het gehele woord in verhouding sneller is geworden voor de ouderen.

Taakeisen

In hoofdstuk 3, laat ik zien dat jong volwassenen regelmatig vervoegde werkwoorden ontleden als de taak moeilijker wordt gemaakt door het toevoegen van verwarrende pseudowoorden (bijv. *brengde).* Als echter pseudowoorden werden toegevoegd die makkelijk te herkennen zijn als een niet-bestaand woord, zoals *plimt*, kiezen diezelfde proefpersonen voor dezelfde items voor de andere route: toegang tot het gehele woord. Het lijkt erop dat de taakeisen de manier waarop een woord wordt verwerkt, beïnvloeden. Het ontleden lijkt de veiligste route die wordt gebruikt in een moeilijke situatie.

Woordsoort

Zoals hierboven beschreven, verwerken ouderen morfologisch complexe werkwoorden als één geheel. Hoofdstuk 4 laat zien dat dit wellicht niet het geval is voor alle soorten complexe woorden. Zodra er een lexicale beslissing moet worden genomen over zelfstandige naamwoorden, ontleden de proefpersonen meervoudsvormen met een dominante enkelvoudsvorm, bijvoorbeeld *bruiden,* in de losse morfemen (*bruid* en *-en).* Verschillen in werkwoorden en zelfstandig naamwoorden leiden tot een andere verwerking. Verschillen in frequentie en concreetheid werden uitgesloten, toch blijft het op dit moment onduidelijk waarom naamwoorden wel worden ontleed door ouderen en werkwoorden niet. In ieder geval draagt deze studie bij aan de vele reeds bestaande bevindingen in onderzoek dat ontwikkelings-, gedrags- en neurologische verschillen vastgesteld heeft in de verwerking van werkwoorden en zelfstandig naamwoorden.

Morfologische rijkdom

Talen verschillen in de mate van morfologische complexiteit. Sommige talen hebben geen of maar één of twee meervoudsvormen (bijv. Engels en Nederlands), terwijl anderen meerdere of vele verschillende naamvallen of achtervoegsels hebben om meervoud aan te geven (bijv. Fins en Duits). Hoofdstuk 5 toont aan dat de morfologische complexiteit van een taal een rol speelt bij de manier waarop meervoudsvormen worden verwerkt. Bij het lezen van meervoudsvormen in een morfologisch rijke taal zoals het Duits (dat beschikt over vijf verschillende achtervoegsels en vier verschillende naamvallen), lijken proefpersonen te neigen naar ontleding in de stam en het achtervoegsel in plaats van de gehele woordvorm op te halen uit het geheugen. Dit staat in tegenstelling tot sprekers van het Nederlands die alledaagse meervoudsvormen (bijv. *erwten*) in hun geheel verwerken. Een mogelijke verklaring is dat het ophalen van gehele woordsvormen geen rendabele manier van verwerken is voor morfologisch rijke talen, omdat er ontzettend veel verschillende vormen van één woord mogelijk zijn.

Conclusie

Het onderzoek beschreven in deze dissertatie biedt inzicht in de factoren die een rol spelen bij de verwerking van morfemen. Verwerken mensen morfologisch complexe woorden zoals *groeide* or *bruiden* als gehele woorden of worden ze ontleed in de losse morfemen? Kennelijk zijn de onderliggende processen aan woordbegrip en de representaties in het mentale lexicon flexibel en beïnvloedbaar door de spreker, de situatie, de woordeigenschappen, en de taal.

Deutsche Zusammenfassung

Die meisten geschriebenen oder gesprochenen Äußerungen sind eine Abfolge kleinerer Bestandteile. Während sich die bewusste Aufmerksamkeit von Sprechern vor allem den gebrauchten Worten, ihrer Bedeutung und den Beziehungen zwischen verschiedenen Worten richtet, beschäftigen sich viele Linguisten mit noch kleineren Bestandteilen von Sprache. Man sieht leicht, dass Worte wie *Dampfschifffahrtsgesellschaft* aus mehreren Teilen bestehen. Es ist schwerer zu erkennen, dass das gleiche auch für das Wort *gebeugt* gilt. Die Vorsilbe -*ge* und die Nachsilbe -*t* sind Morpheme, die an den Stamm *beug* angehangen werden. Als eine der kleinsten linguistischen Einheiten können Morpheme sowohl die Bedeutung als auch die grammatische Funktion eines Wortes verändern. Im Fall von *gebeugt* deuten *ge*- und -*t* darauf hin, dass es sich um die Partizip-Form des Wortes *beugen* handelt. Es herrscht Uneinigkeit darüber, ob Worte, die aus mehreren Morphemen bestehen (z.B. *glänzte* oder *Erbsen*), als komplette Worte gespeichert und verarbeitet werden oder ob sie jedes Mal, wenn sie gebraucht werden, erneut in ihre Bestandteile zerlegt werden.

So genannte Zwei-Routen-Modelle gehen davon aus, dass sowohl Zerlegung als auch Komplett-Zugriff bei der Wortverarbeitung stattfinden. Einige dieser

Modelle schlagen vor, dass für Worte mit mehreren Morphemen wie *glänzte* beide Routen zur selben Zeit aktiviert werden und dass diejenige gewinnt, die als erste einen geeigneten Eintrag im mentalen Lexikon (eine Art Wörterbuch im Gehirn) findet. Welche der beiden Routen schneller ist, hängt von mehreren Faktoren ab. Einer dieser Faktoren ist Worthäufigkeit. Wenn ein Wort im mentalen Lexikon gespeichert ist, hängt die Zeit, die man braucht um es abzurufen, davon ab, wie häufig es in der Sprache auftritt.

Diese Dissertation untersucht weitere Faktoren und wie sie das Verstehen von gebeugten Verben und Substantiven beeinflussen. Ein Hauptergebnis ist, dass junge Leute regelmäßige („schwache") Verbformen anders verarbeiten als ältere Leute (Kapitel 2 und 3). Während junge Leute Worte wie *glänzte* in *glänz* und *-te* zerlegen, greifen ältere Leute auf diese als komplette Vollformen zu. Dafür gibt es mehrere mögliche Erkläungen, zum Beispiel Erfahrungsunterschiede mit gebeugten Formen oder altersbedingte Unterschiede im Arbeitsgedächtnis.

Erfahrung mit gebeugten Formen

Studien haben gezeigt, dass die strukturelle Organisation des mentalen Lexikons davon beeinflusst wird, wie häufig man bestimmten Worten in der Sprache begegnet. Da ältere Leute im Laufe ihres Lebens viel öfter gebeugte Formen gehört und benutzt haben, ist es möglich, dass es ihnen leichter fällt, diese Formen als komplette Vollformen zu erkennen. Junge Leute hingegen waren diesen gebeugten Formen möglicherweise noch nicht oft genug ausgesetzt, sodass die Zerlegungsroute schneller einen passenden Eintrag findet.

Arbeitsgedächtnis

Eine weitere mögliche Erklärung für die Altersunterschiede sind Unterschiede im Arbeitsgedächtnis, dessen Kapazität mit dem Alter abnimmt. Es ist denkbar, dass die Prozesse, die nötig sind um gebeugte Worte zu zerlegen und wieder zusammenzufügen, so sehr verlangsamt werden, dass die Vollzugriff-Route in älteren Leuten schneller ist.

Anforderungen der Aufgabe

Die Ergebnisse von Kapitel 3 weisen darauf hin, dass junge Versuchspersonen reguläre Verbformen zerlegen, wenn die Aufgabe durch verwirrende Pseudowörter (z.B. *denkte*) schwer gemacht wird. Die selben Versuchspersonen griffen auf die selben Worte jedoch über die Vollzugriff-Route zu, wenn die Pseudowörter einfach zu erkennen waren (z.B. *plits*). Anscheinend beeinflussen die Anforderungen der Aufgabe, wie gebeugte Formen verarbeitet werden. Die Zerlegungsroute erscheint als die sichere Alternative, wenn die Bedingungen schwierig sind.

Wortart

Wie beschrieben verarbeiteten ältere Versuchspersonen auf morphologisch komplexe Vergangenheitsformen von Verben als komplette Vollformen. Kapitel 4 zeigt, dass dies womöglich nicht für alle Arten von gebeugten Worten gilt. Wenn es sich bei den Testworten um Substantive im Singular und Plural handelte, zerlegten die selben Versuchspersonen singular-dominante Worte (z.B. *Nasen*) in die einzelnen Morpheme (*Nase* + *-n*). Anscheinend werden Substantive und Verben unterschiedlich verarbeitet. Nachdem Unterschiede in der Häufigkeit und in der Konkretheit ausgeschlossen wurden, sind die genauen Ursachen für die unterschiedliche

Verarbeitung weiterhin unklar. Die Studie liefert jedoch einen weiteren Beitrag zu den bereits bestehenden Untersuchungen bezüglich der unterschiedlichen Verarbeitungen von Verben und Substantiven.

Morphologische Vielfalt

Sprachen unterscheiden sich in Bezug darauf, wie morphologisch komplex sie sind. Manche Sprachen haben nur eine oder zwei Pluralformen (wie Englisch oder Niederländisch), während andere mehrere Fälle haben oder den Plural auf viele verschiedene Weisen ausdrücken (z.B. Finnisch oder Deutsch). Kapitel 5 verdeutlicht, wie morphologische Komplixität die Verarbeitung von Plural-Formen beeinflusst. Sprecher einer morphologisch reichen Sprache wie Deutsch (fünf Plural-Morpheme und vier verschiedene Fälle) scheinen alle Pluralformen in ihren Stamm und das Plural-Morphem zu zerlegen. Dies steht im Gegensatz zum Niederländischen; niederländsche Versuchspersonen verarbeiteten sehr häufige Pluralformen (z.B. Erbsen) als komplette Vollformen ohne Zerlegung. Eine mögliche Erklärung hierfür ist, dass in einer morphologisch reichen Sprache mit zahlreichen möglichen Formen pro Wort die Vollform-Speicherung und der Vollform-Zugriff eine sehr unökonomische Verarbeitungsweise wäre.

Zusammenfassung

Die in dieser Dissertation beschriebenen Experimente gewähren Einblick in die Faktoren, die morphologische Verarbeitung beeinflussen. Werden morphologisch komplexe Formen wie *glänzte* oder *Erbsen* als ganze Vollformen verarbeitet oder werden sie in ihre Bestandteile zerlegt? Offenbar sind sowohl die Organisation des mentalen Lexikons als auch die Vorgänge, die dem Sprachverstehen unterliegen, flexibel. Wie ein komplexes Wort verstanden wird, hängt ab vom Sprecher, von der Situation, von der Sprache und vom Wort selbst.

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People often joke about the impact that a PhD has on your life by comparing it to a long journey or a life partner. For me, my dissertation is like my baby. At first, it seems like a great idea and lots of fun, but after the first sleepless nights, you wonder what you got yourself into. Now that it's done, I'm excited and relieved but also kind of sad that it's over.

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Curriculum Vitae

Jana Reifegerste was born in 1986 in Schwerin, Germany. After obtaining her Abitur diploma in 2005, she started studying Psychology at Leipzig University. In 2008, Jana transferred to McGill University where she obtained a bachelor's degree (Dean's Honour List) in Psychology, Behavioural Science, and Linguistics in 2010. In the same year, she started her PhD at the Max Planck Institute for Psycholinguistics under the supervision of Antje Meyer and Pienie Zwitserlood. The results of her PhD research are described in this thesis. Jana is currently working as a Research Fellow at the Potsdam Research Institute for Multilingualism in Germany.

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