Analogical effects in reading Dutch verb forms

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Abstract

Previous research has shown that the *production* of morphologically complex words *in isolation* is affected by the properties of morphologically, phonologically, or semantically similar words stored in the mental lexicon. We report five experiments on Dutch which show that *reading* an inflectional word form *in its linguistic context* is also affected by analogical sets of formally similar words. Self-paced reading Experiments I to III show that an incorrectly spelled suffix delays readers less if the incorrect spelling is in line with the spelling of verbal suffixes in other inflectional forms of the same verb. Self-paced reading Experiments IV and V show that formally similar words with different stems affect the reading of incorrect suffixal allomorphs on a given stem. These intra- and interparadigmatic effects in reading may be due to on-line processes, or to the storage of incorrect forms resulting from analogical effects in production.

Introduction

Many studies have shown that the mental lexicon does not only contain representations for morphologically simple words and for morphologically complex words with unpredictable characteristics, but also for completely regular morphologically complex words, including inflections (e.g., Stemberger, & MacWhinney, 1986, 1988; Baayen, Dijkstra, & Schreuder, 1997; Alegre, & Gordon, 1999; Sandra, Frisson, & Daems, 1999; Bybee 2000; Frisson & Sandra, 2002; Baayen, McQueen, Dijkstra, & Schreuder, to appear). Other studies have shown that these stored words and word forms may affect each other's production as well as the formation of new morphologically complex forms (e.g., Skousen, 1989; Krott, 2001; Krott, Baayen, & Schreuder, 2001; Ernestus & Baayen, 2003, to appear). For instance, Krott and colleagues (Krott, 2001; Krott, Baayen, & Schreuder, 2001) showed that the probability and the speed with which a speaker chooses a given interfix for a new compound highly correlates with the frequency of the interfix among the existing compounds with the same initial constituent as the new compound. If the initial constituent is followed by a given interfix in many existing compounds, speakers often choose this interfix, and when they do so, they react fast. Thus the Dutch noun *macht* 'power' is followed by the interfix *s* in 71 out of 78 existing compounds (CELEX, Baayen, Piepenbrock, & Gulikers, 1995), and most speakers of Dutch tend to create the new compound *machtswoede* out of *macht* 'power' and *woede* 'anger', by means of the interfix *s*. Moreover, when they do so, they are faster than when they choose no or another interfix. The studies on analogical effects have concentrated on the *production* of word forms in *isolation*. In the present study, we investigated whether analogical effects may also arise in *comprehension*, even when the words are presented in *meaningful linguistic contexts*.

During comprehension, language users may retrieve morphologically complex forms as complete units from their mental lexicon, or they may retrieve the morphemes of these words as separate units. The retrieval process may activate not only the forms themselves or their components, but also morphological, phonological, semantic, and orthographic neighbors, as has been shown, for instance, by Pisoni, Nusbaum, Luce, and Slowiaczek (1985), and Schreuder and Baayen (1997). It is not inconceivable that the co-activated neighbors affect

comprehension, and therefore that analogical effects arise in word comprehension.

Analogical effects may arise especially when word forms are presented outside their linguistic contexts, and participants are requested to react as fast as possible. If speakers cannot prepare the word forms on the basis of the preceding linguistic context, but they nevertheless have to react fast, they may take advantage of relations between word forms stored in their mental lexicon that they would not rely on under normal circumstances. In the present study, we investigated whether speakers show analogical effects in comprehension even when the relevant word forms are presented in meaningful linguistic contexts, and there is no time pressure.

Theoretically, the production or comprehension of a word form may be affected by word forms containing the same stem and by words containing other stems. For instance, the processing of a simple past may be affected by other forms of the same verb, for instance, its simple present, and by the forms of other verbs. In this paper, we study both these types of analogical effects, to which we refer as *intra*paradigmatic and *inter*paradigmatic effects, respectively. That is, we address the question of whether the comprehension of one word form is affected by the other forms of the same word (intraparadigmatic analogy) and by the forms of other words (interparadigmatic analogy).

In this study, we focussed on reading (as opposed to auditory word comprehension). Using the self-paced reading paradigm, we presented words in meaningful linguistic contexts, and we measured the reading times for these words and for the following words. Our test case were verb forms in Dutch.

In Table 1, we schematically present the orthographic and phonological forms of regular verb paradigms in Dutch. We distinguish two types of regular verbs: *t*-supporting verbs and *d*-supporting verbs. The stems of *t*-supporting verbs end in unvoiced obstruents in the infinitive (in which the stem is followed by *-en* [ən]), and nearly all their inflectional suffixes contain the grapheme *t* and the sound [t]. The stems of *d*-supporting verbs, in contrast, end in all types of segments in the infinitive, except unvoiced obstruents. Some of their inflectional suffixes contain [d] or *d*, and it is only the third person singular present tense suffix which is spelled with *t*. Note that the classification of obstruent-final verb stems as *t*-supporting or *d*-supporting verbs has to be based on the infinitive, and that it cannot be based on forms

in which the stem is word-final or is followed by consonantal suffixes, since all obstruents in Dutch are unvoiced in syllable-final position (Final Devoicing), and voiced before voiced plosives (Regressive Voice Assimilation). The paradigms of the *t*-supporting verb *krassen* and the *d*-supporting verb *lozen* are given as examples in Table 2. The phonological forms of *lozen* show that the spelling of the stem-final obstruent does not reflect its actual voice realization in all forms.

INSERT TABLES 1 AND 2 ABOUT HERE

Dutch also has completely irregular verbs with simple pasts and past-participles that are not signaled by suffixes, but by segmental changes in the verbal stem. For instance, the forms of the irregular verb *wegen* 'to weigh' are *weeg* [ʋex], *weegt* [ʋext], *wegen* [ʋeɣən], *woog* [ʋox] (singular simple past), *wogen* [ʋoɣən] (plural simple past), *wegende* [ʋeɣəndə], and *gewogen* [xəʋoɣən] (past-participle). These irregular verbs are similar to *t*-verbs in that only the present participle contains a suffix with *d*.

In Experiment I to III, we investigated the role of intraparadigmatic analogical effects in reading Dutch verb forms. We presented readers with third person singular present tense forms embedded in sentences. The verb form was either spelled correctly with *t* (e.g., *krast*), or incorrectly with *d* (e.g., *krasd*). Incorrect *d* is not supported by the inflectional forms of *t*-supporting verbs or irregular verbs, since, except for the present participle, they do not contain suffixes with the sound [d] or the grapheme *d*. In contrast, incorrect *d* does receive support from the inflectional forms of *d*-supporting verbs, since most of them contain *d* or [d]. We therefore expect that if intraparadigmatic analogy affects reading, readers should have more problems with incorrect *d* on the singular present tense forms of *t*-supporting verbs and irregular verbs than on *d*-supporting verbs.

In Experiment IV and V, we focused on interparadigmatic effects in reading. Our starting point for these experiments is a study by Ernestus & Baayen (2003, to appear) which documents the role of interparadigmatic effects in the production of simple past tenses in Dutch. According to the rule assumed in the phonological literature, and also according

to the orthographic conventions, simple pasts in Dutch are created by suffixing -[tə] *-te* to verbal stems that end in unvoiced obstruents in the infinitive (*t*-supporting verbs), and by suffixing *-de* to all other stems (*d*-supporting verbs). Notwithstanding this simple deterministic rule, Ernestus and Baayen (in press) language users also base their choice between the two allomorphs on the stems that are phonologically similar to the relevant verb stem, henceforth the phonological neighbors. If the majority of phonological neighbors end in unvoiced obstruents before vowel-initial suffixes, speakers tend to add *-te* to new and existing stems. Conversely, if the majority of phonological neighbors end in voiced obstruents before vowels, speakers tend to add *-de*. Thus, according to the simple deterministic rule, the simple pasts for the verbs *schrob* [sxrɔp] 'scrub' and *zaag* [zax] 'saw' are created by adding *-de* to these stems, since the infinitives are *schrobben* [sxrɔbən], with a voiced [b], and *zagen* [zaɣən], with a voiced [ɣ]. Neverhteless, speakers erroneously tend to add *-te* to *schrob*, because the majority of phonological neighbors, such as *stop* [stɔp] 'stop', *klop* [klɔp] 'knock', *klap* [klɑp] 'clap', and *sloep* [slup] 'sloop', end in unvoiced obstruents before vowel-initial suffixes. In contrast, speakers do not add *-te* to *zaag*, because the majority of phonological neighbors, including *klaag* [klax] 'complain', *daag* [dax] 'dawn', *pleeg* [plex] 'commit', and *traag* [trax] 'slow', end in voiced obstruents when followed by vowels word-internally.

The relevant phonological neighbors are the stems ending in the same type of rhyme. A Classification Tree (CART: Breiman, Friedman, Olshen & Stone, 1984) grouped the final rhymes of 1697 nouns, verbs, and adjectives ending in an obstruent into 11 gangs such that rhymes with a similar preference for a voiced final obstruent are grouped together. Table 3 presents the 11 analogical gangs, characterized by the final rhymes of their stems as realized in isolation. The segments enclosed by the first pair of brackets represent the possible vowels in the final rhymes of that gang, while the segments enclosed by the second pair of brackets represent the possible pre-final consonants, with a hyphen indicating the possibility of the absence of a pre-final consonant. The final pair of brackets encloses the set of possible final obstruents, which are necessarily unvoiced when the stems are presented in isolation. Thus the word *schrob* falls into gang 5, and *zaag* falls into gang 7. Table 3 also lists the proportion of stems in each gang that has voiced final obstruents before vowel-initial suffixes, which represents the gang's analogical support for final voicing. It correlates

with the proportion of participants adding -*de* to pseudo words falling in the gang, and it accounts for the incorrect simple past forms that speakers produce, that is, the forms with a simple past allomorph that is surprising given the generative phonological rule and the Dutch spelling conventions. Speakers tend to select the simple past allomorph that is supported by the voicing preference of the phonological gang of the verb, irrespective of whether this allomorph is in line with the realization of the stem-final obstruent of the verb itself in the infinitive. Moreover, speakers select the incorrect allomorph more often if the analogical support for this allomorph is larger.

INSERT TABLE 3 ABOUT HERE

In our study we investigated readers' reactions to incorrect allomorphs. We expected that incorrect allomorphs delay reading. However, given the production data, we also expected that readers are delayed less when an incorrect allomorph is supported by the analogical gang of the verb than when it is not. This would form evidence for interparadigmatic analogy in reading, since it would show effects from other words, that is, from words belonging to different paradigms.

We now turn to Experiment I, which studies intraparadigmatic effects in reading present tense verb forms. In this experiment we investigate whether an incorrect spelling of the third person present tense suffix as *d*, instead of *t*, delays readers less if the verb is *d*-supporting than if it is *t*-supporting.

Experiment I

Method

Participants. Sixty-two participants, mostly undergraduates at the University of Nijmegen, were paid to take part in the experiment. All were native speakers of Dutch.

Materials and design. We selected the third person singular present tense forms of eight monomorphemic *t*-supporting verbs and eight monomorphemic *d*-supporting verbs (see the

Appendix). The forms were matched for length (on average 4.38 and 4.63 graphemes respectively, $t(14) = -.78, p > 0.10$) and for the log of their frequency (on average 2.44 and 2.36, respectively, $t(14) = .10, p > 0.10$) as reported in the Dutch section of the CELEX lexical database. The forms were embedded in sentences, as illustrated in (1). Each sentence consisted of a subject noun phrase, the verb form, an (object) noun phrase, and a prepositional phrase. Some sentences continued after the prepositional phrase. Each verb form was spelled correctly in one version of the sentence, and misspelled with a *d* instead of a *t* in another version of the sentence. Apart from the final grapheme of the verb form, the two versions of a sentence were identical (compare 1a with 1b).

(1a) *Het schip loost zijn olie bij de haveningang.*

(1b) *Het schip loosd zijn olie bij de haveningang.*

The ship drains its oil at the harbour-entrance.

'The ship is draining its oil at the entrance of the harbour.'

Since each sentence had two versions, we had a total of 32 experimental sentences. They were divided over two experimental lists, such that each list contained one version of every sentence, and four experimental sentences with misspelled *d*-supporting verb forms, and four experimental sentences with misspelled *t*-supporting verb forms. In addition, the two lists contained 80 filler sentences with 24 incorrectly spelled nouns. In total, 32 of the 96 sentences presented to a participant contained a misspelling. The experimental sentences and the filler sentences were pseudo randomly mixed such that both the correctly and incorrectly spelled *t*-supporting verbs and both the correctly and incorrectly spelled *d*-supporting verbs were evenly distributed over the lists. The order of the sentences was identical in the two lists.

Every sentence in the experiment was followed by a question. These questions stimulated the participants to read the sentences carefully, and to focus on content instead of form. The question that followed the sentences in (1) is presented in (2).

(2) *Is de schipper zeer begaan met het milieu?*

'Does the captain feel much compassion for the environment?'

Before the experiment started, the participants were presented with a practice block of 14 sentences. These practice sentences were similar to the ones in the experiment, and were also followed by questions. They did not contain misspelled words.

Procedure. The participants performed a self-paced reading task. They were tested individually, sitting in a dimly lit room in front of a PC monitor, and a panel with three buttons. The course of a trial was as follows. The participant saw a fixation point, indicating the starting position of all sentences. The participant then pressed the middle button, and a complete sentence was presented on the screen. The letters, however, were replaced by dashes. Only the full stop at the end of the sentence was visible. The participant pressed the middle button, and the dashes of the first word were converted into letters. The participant read this word, and pressed the middle button again, which reconverted the letters of the first word into dashes, and made the second word legible. The participant read this word, pressed the button, and read the following word. This was repeated until the participant had read all words of the sentence. The participant then saw the word *vraag* 'question' for 1.0 second on the screen, followed by the question about the sentence. If the answer to the question was 'yes', the participant pressed the right button. If the answer was 'no', the participant pressed the left button. We measured the time span between the successive button presses, that is, the time a participant needed to read each word in the sentence. In addition, we also registered the responses to the questions.

Half of the participants read the sentences of one list, while the other half read the sentences of the other list. In the instruction, the participants were told that some sentences contained misspellings, that they should ignore those, and that it would be clear which word was intended.

Results. We excluded two participants from the data set, because they answered more than 10% of the questions incorrectly. The remaining participants answered on average 4% of the questions incorrectly. From these participants, we discarded the extremely long (longer than 4000 ms) and extremely short (shorter than 50 ms) reading times. In addition, we excluded the reading times that were more than two standard deviations away from both

the participant and item means for a given position in a given condition. In total, we excluded 33 trials from the remaining participants (1.7%).

Table 4 shows the average reading times for the verb forms that were correctly spelled with *t*, the verb forms incorrectly spelled with *d*, and for the two words immediately following these verb forms. The table distinguishes between the *d*-supporting verbs and the *t*-supporting verbs.

INSERT TABLE 4 ABOUT HERE

We analyzed the data by means of two analyses of variance, one with participants (F_1) and one with items (F_2) as a random variable. The factors in the analyses were Verb type (*d*-supporting verb versus *t*-supporting verb), Correctness (correctly spelled versus misspelled), Position (the verb form itself versus the following word), and Reading speed (the thirty fastest participants versus the thirty slowest). We included the reading times for the word directly following the verb form, since there are often spill-over effects to the following words in self-paced reading experiments (Just, Carpenter & Woolley, 1982). We only took the reading times for the directly following word into account, since Table 4 shows that the reading times for the second following word are hardly affected by the spelling of the verb form. We included Reading speed, since it is possible that only slow readers may notice the misspellings, or that slow readers may show the effects of the misspellings in their reading times for the verb forms themselves, while fast readers may show the effects in their reading times for the following words (see below). If there are intraparadigmatic effects in reading, we expect an interaction of Correctness by Verb type, showing that readers are less delayed by an incorrect *d* if the paradigm of the verb is *d*-supporting.

INSERT TABLE 5 ABOUT HERE

Table 5 presents the main effects and the interactions that were significant in the participant and item analysis. We found the hypothesized interaction of Correctness by Verb type in the participant analysis ($F_1(1, 58) = 3.86, p = .05$; $F_2(1, 14) = 1.29, p > .10$). The partici-

pant analysis also shows a three-way interaction of Correctness by Verb type and Position, which is marginal in the item analysis ($F_1(1,58) = 4.17, p = .05$; $F_2(1,14) = 3.24, p = .09$).

We studied this three-way interaction in more detail by investigating whether both the reading times for the verb forms and for the following words show an interaction of Verb type by Correctness, which is the main focus of our study. The reading times for the verb forms show the interaction ($F_1(1,58) = 5.66, p = .02; F_2(1,14) = 4.12, p = .06$). Correctness is significant for the *t*-supporting verbs ($F_1(1,58) = 12.12, p < .01; F_2(1,7) = 17.804, p < .01$), whereas it is not for the *d*-supporting verbs ($F_1(1,58) = .77, p > 0.10; F_2(1,7) = .56, p > .10$). There is no interaction of Correctness by Verb type at the position of the following word ($F_1(1,58) = .02, p > .10; F_2(1,14) = .12, p > .10$). Correctness is significant by itself ($F_1(1,58) = 13.09, p < .01; F_2(1,14) = 7.42, p = .02$). We see that if the verbal paradigm does not support *d*, incorrect *d* delays the reading of the verb form itself and of the following word. In contrast, if the verb supports *d*, incorrect *d* delays reading times only at the word following the verb form. It does not affect the reading times at the verb form itself.

We also found effects of Reading speed. Most interestingly, there is an interaction of Correctness by Reading Speed ($F_1(1,58) = 12.23; p < .01, F_2(1,14) = 6.73, p = .02$). Incorrect spellings delayed the fast readers by only 11 ms (their average reading times in the correct condition was 286 ms, and in the incorrect condition 297 ms), while they slowed the slow readers by 55 ms (correct condition: 454 ms; incorrect condition: 509 ms). The effect of Correctness for the fast readers is only signficant in the participant analysis ($F_1(1,29) = 4.41, p = .05; F_2(1,14) = 1.44, p > .10$), whereas it is significant in both the participant and the item analysis for the slow readers ($F_1(1,29) = 23.45, p < .01; F_2(1,14) = 13.77, p < .01$).

Discussion. The experimental results suggest that readers have more problems with an incorrect *d*, if the inflectional paradigm of the verb does not support *d*. This effect of verb type is in line with our hypothesis of intraparadigmatic effects in reading. An alternative explanation of the attested effect is possible, however. The final grapheme sequences of the *d*-supporting verb stems are regularly followed by word-final *d*, whereas the final grapheme sequences of the *t*-supporting verb stems never are (see Table 6, which gives the grapheme sequences at the end of the verb stems in the experiment, and the frequencies with which

these sequences are followed by word-final *t* and word-final *d* according to CELEX). Readers are familiar with the grapheme sequences in the misspelled *d*-supporting verb forms, whereas they are not with the grapheme sequences in the misspelled *t*-supporting verb forms. Our results, therefore, do not necessarily form evidence for intraparadigmatic effects. They may show the effects of the frequencies of the grapheme sequences in the two types of misspelled forms.

INSERT TABLE 6 ABOUT HERE

We designed Experiment II in order to test whether there is also a difference between verbs that do and that do not support *d*, if their final grapheme sequences are equally often followed by *d*. In this experiment, we compared *d*-supporting verbs with completely irregular verbs. The inflectional forms of completely irregular verbs are neutral to the orthographic form of the third person singular present tense, since they do not take suffixes with [d], [t], *d*, or *t*, apart from the present participle, which contains [d] *d*. In the following, we will therefore refer to these completely irregular verbs as neutral verbs. We selected *d*-supporting verbs and neutral verbs that end in the same types of rhymes so that their final grapheme sequences are approximately equally often followed by *d* as well as by *t*. We hypothesize that if the within-paradigm neighbors affect the reading of a misspelled verb form, the spelling of a present tense form with *d* should cause fewer problems for *d*-supporting verbs than for neutral verbs.

Experiment II

Method

Participants. Forty native speakers of Dutch were paid for their participation. They were undergraduate students at the University of Nijmegen, and had not participated in Experiment I.

Materials and design. We selected twenty pairs of monomorphemic verbs, each consisting of a *d*-supporting verb and a neutral verb (see the Appendix). The verbs of each pair end in exactly the same obstruent, which, in the majority of cases, is preceded by a vowel of the same phonological length (long or short), so that the final grapheme sequences of the two verbs are approximately equally often followed by *d* as well as by *t* (cf Table 3). For instance, we formed the pair *pleeg* - *weeg*. The verb *pleeg* 'commit' is a *d*-supporting verb, while *weeg* 'weigh', with *woog* [ʋox] as simple past and *gewogen* [ɣəʋoɣən] as past participle, is a neutral verb.

The third person singular present tense forms of the selected *d*-supporting and neutral verbs are of approximately the same length (on average 5.40 and 5.45 graphemes, respectively, $t(38) = -1.24, p > .10$) and log frequency (on average 4.58 and 4.53 respectively, $t(38) = .10, p > .10$). The verbal forms were embedded in sentences of the same structure as the sentences in Experiment I. Each sentence was followed by a question.

We constructed two experimental lists such that experimental items spelled incorrectly in one list were spelled correctly in the other list, and vice versa. In each list the forty experimental sentences were pseudo randomly mixed with 100 filler sentences, some of which contained misspelled nouns. In total, 54 of the 140 sentences in a list contained a misspelling, including ten forms of *d*-supporting verbs, and ten forms of neutral verbs. Each list was preceded by 14 practice sentences. The order of the sentences was the same in the two lists.

Procedure. The procedure was the same as in Experiment I.

Results. We excluded one participant from the data set, since this participant answered less than 90% of the questions correctly. We also excluded three participants because of their excessively long reading times (overall mean > 600 ms). Finally, we excluded 53 reading times (1.2 % of the remaining reading times) that were more than two standard deviations away from both the participant and item means for a given position in a given condition. Table 7 shows the average reading times for the correctly and incorrectly spelled verb forms, and the two following words.

INSERT TABLE 7 ABOUT HERE

We analyzed the reading times by means of a participant and an item analysis of variance, with Verb type (*d*-supporting verb versus neutral verb), Correctness (correctly spelled versus misspelled), Position (the verb form itself or the following word), and Reading speed (the 18 fastest participants versus the 18 slowest participants) as the independent variables. We only considered the reading times for the verb form itself and the directly following word, since the spelling of the verb form hardly affected the reading times for the second following word (see Table 7). The main effects and interactions that are significant in the participant and item analysis are presented in Table 8. As hypothesized, we found a significant interaction of Verb type by Correctness ($F_1(1, 34) = 12.70, p < .01; F_2(1, 34) = 4.88, p = .03$). If a *d*-supporting verb was misspelled, this misspelling did not affect the reading times ($F_1(1, 34) = 2.63, p > .10; F_2(1, 19) = 1.42, p > .10$). If, in contrast, neutral verbs were misspelled, the misspelling caused a significant delay ($F_1(1, 34) = 24.09, p < .01; F_2(1, 19) = 12.62, p < .01$).

INSERT TABLE 8 ABOUT HERE

Discussion. Readers did not delay when a *d*-supporting verb was incorrectly spelled with *d*, whereas they did delay significantly when a neutral verb was incorrectly spelled with *d*. The neutral verbs and the *d*-supporting verbs in the experiment end in highly comparable grapheme sequences, and the attested effect of verb type therefore cannot be due to the frequencies with which these sequences occur with *d* and *t*. The results form strong support for the hypothesis of intraparadigmatic effects in reading.

Theoretically, however, there is yet another possible account of the data. If the third person singular present tense form of a *d*-supporting verb is spelled incorrectly with *d*, it is very similar to the corresponding simple past form. The two forms only differ in that the simple past has an extra *e* (see Tables 1 and 2). For instance, incorrect *pleegd* is very similar to the simple past form *pleegde*. The misspelled forms of neutral verbs, on the contrary, are not similar to the corresponding simple past forms, because these simple pasts are irregular. Thus incorrect *weegd* is not highly similar to *woog*. Possibly, readers had fewer problems with the misspelled forms of *d*-supporting verbs, because they interpreted these misspelled

forms as misspelled simple pasts.

In Experiment III, we tested whether the attested difference between *d*-supporting and neutral verbs is also present when the interpretation of the misspelled present tense forms as simple pasts is unlikely. Experiment III differed from Experiment II in two respects. First, the sentences started with an adverb. Sentences containing *d*-supporting verbs started with adverbs such as *nu* 'now', *tegenwoordig* 'nowadays', and *morgen* 'tomorrow', which tend to occur in sentences in the present tense or the future, and therefore introduce a bias against the interpretation of the verb form as a simple past. Second, the experiment included 20 *t*-supporting verbs. These *t*-supporting verbs give us the opportunity to replicate the results of Experiment I. Besides, they allow us to investigate interparadigmatic analogy in reading. So far, we have focused on analogical effects induced by the inflectionally related forms (intraparadigmatic analogy). As mentioned above, the reading of a verb form might also be affected by forms belonging to other verb paradigms that are phonologically or orthographically (henceforth formally) similar. If so, the effect of an incorrect *d* is expected to be larger for the *t*-supporting verbs than for the neutral verbs in the experiment, since the neutral verbs are formally similar to *d*-supporting verbs, and they may receive support from these verbs for incorrect *d*. Hence, a difference between *t*-supporting verbs and neutral verbs may result from interparadigmatic effects in reading.

Experiment III

Method

Participants. Forty native speakers of Dutch were paid for their participation. Most of them were undergraduate students of the University of Nijmegen. None of them had participated in Experiment I or II.

Materials and design. We selected twenty monomorphemic *t*-supporting verbs in addition to the twenty monomorphemic *d*-supporting verbs and the twenty monomorphemic neutral verbs from Experiment II (see the Appendix). The third person singular present tense forms of these verbs are approximately of the same length (on average 5.65, 5.20, and 5.40

graphemes respectively, verb type: $F(2, 57) = 2.57, p = .09$) and log frequency of occurrence (on average 4.53, 4.31, and 4.58, verb type: $F(2, 57) = .17, p > .10$). We embedded the verb forms in sentences consisting of an adverb, the present tense verb form, a subject noun phrase of two words, and at least three more words (see example 3). The adverbs in sentences with *d*-supporting verbs introduce a bias against interpreting the verb form as a simple past.

(3) Sentence: *Morgenochtend reist mijn oma naar Portugal af.*
Tomorrow morning sets my grandmother for Portugal off.
'Tomorrow morning my grandmother will set off for Portugal.'
Question: *Heeft deze vrouw kleinkinderen?*
'Does this woman have grandchildren?'

We constructed two experimental lists that were identical, except that the experimental items spelled incorrectly in one list were spelled correctly in the other list. Each list contained 10 incorrectly spelled forms of each verb type. The experimental items in a list were pseudo randomly mixed with 65 filler sentences, none of which contained misspellings. Both lists were preceded by 14 practice sentences.

Procedure. The procedure was the same as in Experiments I and II.

Results. We included all participants in the data set, since they all answered more than 90% of the questions correctly. We excluded the 355 (1.5%) reading times that were more than two standard deviations away from both the participant and item means for a given position in a given condition. Table 9 shows the reading times for the correctly and incorrectly spelled verb forms, the following word, and the second following word.

INSERT TABLE 9 ABOUT HERE

We analyzed the data by means of a participant and an item analysis of variance, with as independent variables: Verb type (*d*-supporting verb, *t*-supporting verb, neutral verb),

Correctness (correctly spelled versus misspelled), Position (the verb form itself, the immediately following word, or the second following word), and Reading speed (the twenty fastest participants versus the twenty slowest participants). We incorporated the second following word, since the means suggest that the spelling of the verb form also affected the reading times for this word (see Table 9). In contrast to the first two experiments, this second word was the subject of the sentence, and hence syntactic integration of the subject and the verb form took place at this position.

INSERT TABLE 10 ABOUT HERE

Table 10 shows the significant main effects and interactions. The interaction that we expected between Correctness and Verb Type was highly significant in the participant analysis ($F_1(1, 37) = 14.64, p < .01$) and marginally significant in the item analysis ($F_2(1, 57) = 2.87, p = .07$). A separate analysis of the *d*-supporting verbs showed an effect of Correctness in the participant analysis only ($F_1(1, 38) = 5.35, p = .03; F_2(1, 19) = 1.84, p = .19$). The neutral verbs showed an effect of Correctness in both the participant and the item analysis ($F_1(1, 38) = 24.64, p < .01; F_2(1, 19) = 6.37, p = .02$), and so did the *t*-supporting verbs ($F_1(1, 38) = 69.48, p < .01; F_2(1, 19) = 1.92, p < .01$). Since the participant analysis showed a main effect of Correctness for both the *d*-supporting verbs and the neutral verbs, we conducted an analysis over these two verb types only in order to test for a difference between the two verb types. This analysis showed an interaction of Verb type by Correctness in the participant analysis ($F_1(1, 35) = 5.12, p = 0.03; F_2(1, 38) = 0.48, p > 0.10$). Thus, as in Experiment II, Correctness had a smaller effect on the *d*-supporting verbs than on the neutral verbs. In order to investigate whether the effect of Correctness is larger for the *t*-supporting verbs than for the neutral verbs, we conducted an analysis over these two verb types only. This analysis showed that the interaction of Correctness by Verb type is significant in the participant analysis ($F_1(1, 38) = 16.30, p < .01; F_2(1, 38) = 2.64, p > .10$).

Discussion. Even though the misspelled forms of the *d*-supporting verbs were unlikely to be interpreted as simple pasts in this experiment, they did not delay reading. In contrast, the

misspelled forms of the neutral verbs did delay reading. We conclude that intraparadigmatic support for *d* facilitates the comprehension of incorrect *d*, and that intraparadigmatic analogy affects reading.

The interaction of Correctness by Verb type in the participant analysis over *t*-supporting verbs and neutral verbs suggests that an incorrect *d* has a larger effect on *t*-supporting verbs than on neutral verbs. This difference may result from interparadigmatic analogy: Reading a verb form may activate the within-paradigm neighbors as well as the formal neighbors, which support *d* in the case of neutral verbs.

In Experiment IV, we further investigated the possibility that the reading of a verb form may be affected by interparadigmatic analogy. This self-paced reading experiment takes as its point of departure the findings by Ernestus and Baayen (2003, to appear), mentioned in the introduction of this paper. Ernestus and Baayen found that speakers of Dutch base their choice between the simple past allomorphs *-de* and *-te* not only on the verb itself but also on the gangs of phonological neighbors. Speakers tend to choose *-de* if the majority of phonological neighbors end in voiced obstruents before vowel-initial suffixes, and they tend to choose *-te* if the majority of neighbors end in unvoiced obstruents before such suffixes, irrespective of the realization of the final obstruent of the verb itself. The relevant gangs of neighbors are those represented in Table 3.

In Experiment IV, participants read sentences with regular simple pasts. These verbs forms had either the simple past allomorph that is prescribed by the Dutch spelling conventions (e.g., *schrobde*, *stopte*), or the incorrect allomorph (*schrobte*, *stopde*). If reading, too, is affected by the phonological gangs defined by Ernestus and Baayen (2003), we expect that the incorrect allomorph delays readers less when it is supported by the phonological gang of the verb. For instance, the phonological gang of words ending in a short vowel and a bilabial plosive favors an unvoiced realization for the final obstruent before vowel-initial suffixes (the support for voicing is .019, see Table 3), and it consequently supports the allomorph *-te*, which typically follows obstruents that are unvoiced in the infinitive. Hence, we would expect that readers have more difficulty with incorrect *stopde* than with incorrect *schrobte*. In what follows, we will refer to verbs of which the correct simple past allomorph is supported by the phonological gang as 'lexically congruent' verbs. Verbs of which the correct

allomorph is not supported by the phonological gang are 'lexically incongruent'. The verb *stop*, which has the simple past *stopte*, is lexically congruent, while *schrob*, with the simple past *schrobde*, is lexically incongruent.

Experiment IV

Method

Participants. Fifty-two native speakers of Dutch were paid to participate in the experiment. Most of them were undergraduate students of the University of Nijmegen. They had not participated in Experiment I, II, III, or in Ernestus and Baayen's simple past production experiments (Ernestus & Baayen, 2001, to appear).

Materials and design. We selected fourteen monomorphemic lexically congruent verbs and fourteen monomorphemic lexically incongruent verbs (see the Appendix). Their third person singular past tense forms are of approximately the same length (on average 6.54 and 6.43 graphemes, respectively, $t(26) = .16, p > .10$) and log frequency (on average 4.14 and 4.03, respectively, $t(26) = .22, p > .10$). We embedded these verb forms in sentences consisting of a subject noun phrase of two words, the simple past form, and at least two other words. The sentences with lexically congruent simple pasts had the same syntactic structures as the sentences with lexically incongruent simple pasts. Each sentence was followed by a question (see example 4).

(4) Sentence: *Deze muur grensde vroeger aan een kleine speeltuin.*
This wall bordered previously on a small playground.
'This wall used to border on a small playground.'
Question: *Is de speeltuin verdwenen?*
'Has the playground disappeared?'

We constructed two experimental lists that were identical, except that experimental items spelled with the correct simple past allomorph in one list were spelled with the incorrect simple past allomorph in the other list, and vice versa. Each list contained fourteen simple

pasts with incorrect allomorphs: seven lexically congruent and seven lexically incongruent verbs. The twenty-eight experimental sentences in each list were pseudo randomly mixed with forty filler sentences, which did not contain misspellings.

Procedure. The procedure was the same as in Experiment I to III, except that the participants did not get the information that some sentences contained misspellings.

Results. We excluded the 109 reading times that were more than two standard deviations away from both the participant and item means for a given position in a given condition (0.8%). Table 11 presents the resulting average reading times for the simple past forms with the correct and the simple past incorrect allomorphs and for the two directly following words, broken for Verb type (lexically congruent versus lexically incongruent) and Correctness. We analyzed the data by means of a participant and an item analysis of variance, with the independent variables Verb type (lexically congruent versus incongruent), Correctness (correct simple past allomorph versus incorrect simple past allomorph), Position (the simple past form itself versus the following word), and Reading speed (the 26 fastest readers versus the 26 slowest readers). We did not include the second word following the verb form because the means suggest that the effect of Correctness at this word is small and independent of Verb Type. If there are interparadigmatic effects in reading, we expect an interaction of Correctness by Verb type.

INSERT TABLES 11 AND 12 ABOUT HERE

Table 12 shows the significant main effects and interactions in the participant and item analysis. We attested the hypothesized interaction of Correctness by Verb type ($F_1(1,50) = 6.20, p = .02$; $F_2(1,26) = 4.43, p = .05$). Correctness affected the reading of the lexically congruent verbs ($F_1(1,50) = 10.65, p < .01$; $F_2(1,13) = 11.22, p < .01$), whose correct allomorph is supported by the formal neighbors. In contrast, Correctness had no main effect on the lexically incongruent verbs ($F_1(1,50) = .34, p > .10$; $F_2(1,13) = 1.14, p > .10$).

Discussion. Experiment IV shows that readers have fewer problems reading an incorrect

simple past allomorph, if this allomorph is supported by the words that are formal neighbors to the verb. We conclude that interparadigmatic analogy affects reading.

The reading of simple past forms may be affected by analogy because interparadigmatic effects are part and parcel of the comprehension process. In addition, interparadigmatic analogy may play a role because speakers of Dutch have not learned to base their choice between the two simple past allomorphs on an explicit deterministic rule: They acquire both allomorphs in spoken language before they learn to spell.

In Experiment V, we tested whether analogical effects also emerge in reading if speakers have explicitly learned to base their choice between allomorphs on a deterministic rule. We investigated the reading of regular past participles. Dutch regular past participles are created by prefixing the verb stem with [ɣə] *ge-*, and suffixing the stem with [t] (see Tables 1 and 2). According to the Dutch spelling conventions, the suffix [t] is spelled as *t* after obstruents that are unvoiced in the infinitive (*t*-supporting verbs), and as *d* after all other segments (*d*-supporting verbs). Since school children learn to base their choice between the two spelling allomorphs on precisely this deterministic rule, and the acoustic realization of the suffix provides no information on its spelling, we might expect that language users' behavior with respect to the spelling of this suffix is rule-based, and that interparadigmatic analogical effects may not appear.

Experiment V

Method

Participants. Eighty-two native speakers of Dutch who had not participated in either Experiments I, II, III, IV, or in Ernestus and Baayen's simple past production experiments (Ernestus & Baayen, 2001, in press) were paid for their participation. Most of them were undergraduate students at the University of Nijmegen.

Materials and design. We selected the regular past participles of sixteen lexically incongruent monomorphemic verbs, and of sixteen lexically congruent verbs (see the Appendix). For half of the lexically congruent and for half of the lexically incongruent past participles, the correct

allomorph is *t*. For the other half, the correct allomorph is *d*. The past participles of the lexically congruent and incongruent verbs are of a similar length (on average 4.25 and 4.38 graphemes, respectively, $t(30) = .38, p > .10$) and log frequency (both on average 1.94, $t(30) = .01, p > .10$). The past participles were embedded in sentences, consisting of a subject phrase of two words, a form of the auxiliary verb *hebben*, an object phrase of two words, the past participle, and two preposition phrases of three words. Each sentence was followed by a question (see example 5).

(5) Sentence: *De kinderen hebben hun namen gekrast in de schutting rond de tuin.*
The children have their names scratched in the fence around the garden.
'The children scratched their names in the fence around the garden.'
Question: *Konden de kinderen toen al schrijven?*
'Did the children by then know how to write?'

We constructed two experimental lists that were identical, except that experimental items spelled incorrectly in one list were spelled correctly in the other list. The two lists contained the same number of misspelled past participles of each kind. The 32 experimental sentences (congruent with *t*, congruent with *d*, incongruent with *t*, incongruent with *d*) in each list were pseudo randomly mixed with 40 filler sentences, which did not contain misspellings. Both lists were preceded by the same 14 practice sentences.

Procedure. The procedure was the same as in Experiment IV.

Results. We excluded the 386 (1.2%) reading times that were more than two standard deviations away from both the participant and item means for a given position in a given condition. Table 13 presents the resulting average reading times for the past participles spelled with the correct and the incorrect allomorph, and the two following words. We analyzed the data by means of analyses of variance with the independent variables Verb type (lexically congruent versus incongruent), Correctness (correct versus incorrect allomorph), Position (the past participle itself versus the following word), and Reading speed (the 41 fastest readers versus the 41 slowest readers). Again, we disregarded the second word following the verb form since

the mean reading times for this word seems unaffected by Correctness. Table 14 lists the significant main effects and interactions in the participant and item analyses. The relevant interaction of Verb type by Correctness emerged as statistically significant in the participant analysis ($F_1(1, 80) = 4.90, p = .03$), but not in the item analysis ($F_2(1.30) = 1.25, p > .10$).

INSERT TABLES 13 AND 14 ABOUT HERE

Given this interaction in the participant analysis, we analyzed the sentences with lexically congruent and the sentences with lexically incongruent verbs separately. The lexically incongruent verbs mirrored the interaction of Correctness by Position from the overall analysis in the item analysis ($F_1(1, 80) = 3.04, p = .09; F_2(1, 15) = 10.48, p < .01$). Correctness did not affect the reading of the word directly following the past participle ($F_1(1, 80) = .43, p > .10; F_2(1, 15) = .83, p > .10$), but it did affect the reading of the past participle itself ($F_1(1, 80) = 4.03, p = .05; F_2(1, 15) = 4.15, p = .06$). Participants actually read *faster* when the past participle of a lexically incongruent verb was spelled with the incorrect allomorph than when it was spelled with the correct allomorph. In other words, the incorrect allomorph accelerated the reading of the lexically incongruent verbs.

The sentences with lexically congruent verbs mirrored the interaction of Correctness by Position and Reading speed from the overall analysis ($F_1(1, 80) = 3.38, p = .07; F_2(1, 15) = 3.65, p = .08$). Participants were not affected by the Correctness of the allomorph when they read the past-participles themselves ($F_1(1, 80) = .07, p > .10; F_2(1, 15) = .20, p = .66$). When reading the following word, slow readers were affected by the spelling (interaction of Correctness by Reading speed: $F_1(1, 80) = 6.48, p = .01; F_2(1, 15) = 4.06, p = .06$; Correctness for the slow readers; $F_1(1, 40) = 5.95, p = .02; F_2(1, 15) = 7.99, p = .01$). They read past participles faster when they were spelled correctly. Fast readers were not affected by Correctness ($F_1(1, 40) = 5.95, p > .1; F_2(1, 15) = .15, p > .10$).

Discussion. The data suggest that an incorrect allomorph of the past participle suffix accelerates reading when it is supported by the formal neighbors of the verb. When it is not

supported, it delays slow readers. This finding is in line with the hypothesis that interparadigmatic analogy affects reading.

It is not surprising that slow readers in particular suffer from an incorrect allomorph on the past participles of lexically congruent verbs. Past participles in Dutch are marked by the suffix *t* or *d* as well as by the prefix *ge* (see Tables 1 and 2). Fast readers may not read the final grapheme of a past participle carefully, since this grapheme does not provide them with new information. They know that the relevant form is a past participle because of the prefix *ge*. Slow readers, on the other hand, may read the whole form, or may read it more precisely, and they may observe the correctness of the allomorph.

In the item analysis, the interaction of Verb type by Correctness is not significant. A possible reason is that Verb type may be relevant only for the incorrect allomorph *d*. Slow readers delayed 62 ms on the word following a lexically congruent past-participle with incorrect *d* (average reading time for the following word is 461 ms in case the verb form is correct, and 523 ms in case it is incorrect; Correctness: $F_1(1, 40) = 6.04, p = .02; F_2(1, 7) = 7.52, p = .03$), while they hardly delayed (19 ms) on the word following a lexically congruent past-participle with incorrect *t* (average reading time for the following word is 445 ms in case the verb form is correct, and 464 ms in case it is incorrect; Correctness: $F_1(1, 40) = 1.02, p > .10; F_2(1, 7) = 1.54, p > .10$). A possible explanation for this difference between incorrect *d* and *t* is that past participles are always realized with [t]. Readers may only delay when the incorrect allomorph deviates from the pronunciation of the suffix. Analyses of variance including the shape of the correct allomorph (*t* or *d*) as a factor should reveal the difference between *t* and *d*. If our explanation is correct, it should yield a four-way interaction of Correctness by Verb Type, Reading speed, and Allomorph shape. We did not carry out this analysis, since the data set is too small to provide evidence for four-way interactions. We could not enlarge the data set, since the set of Dutch monomorphemic lexically incongruent verbs is highly restricted.

We tentatively conclude that the phonological gangs defined in Ernestus and Baayen (2003) also affect the reading of incorrect past participles. Though we found interparadigmatic analogical effects also in the reading of simple pasts, this result is not self-evident. It suggests that interparadigmatic effects may also arise when speakers have explicitly learnt

to base their choice between two allomorphs on a deterministic rule.

General discussion

This study investigated the role of intra- and interparadigmatic analogy in the reading of Dutch inflectional forms. In three self-paced reading experiments, present tense forms were either spelled correctly with the suffix *t*, or misspelled with the suffix *d*. All three experiments show that an incorrect *d* causes longer delays when the verb does not take simple past or past participle suffixes with *d* or [d]. We conclude that the reading of a verb form is affected by the formal characteristics of the within-paradigm neighbors (intraparadigmatic analogy). In Experiments IV and V, participants read simple pasts and past participles. According to the spelling conventions of Dutch, these forms should be spelled with a suffix containing either *d* or *t*, depending on the phonological characteristics of the stem. Participants read the forms with the correct allomorph, or with the allomorph that is incorrect given the phonological shape of the stem. The results, especially from the simple past experiment, show that an incorrect allomorph causes shorter delays if there are more formally similar stems for which the allomorph is appropriate than for which it is inappropriate. We conclude that both intra- and interparadigmatic analogy affect the reading of inflected verb forms in Dutch. These analogical effects arose even though the words were presented in meaningful linguistic contexts. This suggests that the analogical effects are part and parcel of the comprehension process.

Dutch has an almost perfect one-to-one relation between sound and grapheme in Dutch (the phonological principle). Word-final *d*, which is realized as [t], is one of the systematic exceptions. Given this nearly perfect one-to-one relation, we may expect that the more an incorrect spelling deviates from the pronunciation of the word, the more Dutch readers may have problems processing this spelling. The misspelling *d* of the suffix [t] investigated in Experiments I to III violates the phonological principle, whereas the correct spelling *t* does not. Nevertheless, the incorrect *d* did not increase the reading times when it was supported by the within-paradigm neighbors of the verb form. In Experiment V, the incorrect allomorph *d* also violated the phonological principle. Here we found that when this incorrect allomorph received support from the formal neighbors, the reading times were even shorter for this

incorrect allomorph than for the correct allomorph *t*. We conclude that the analogical effects are so large that readers are not delayed by analogically supported incorrect spellings and incorrect allomorphs, even when these incorrect forms violate the phonological principle.

So far, we have left it an open question to which extent orthographic similarity drives the analogical effects that we report in this paper. For Experiments IV and V, we determined the interparadigmatic support for an allomorph on the basis of the phonological neighbors. Since the relation between sound and grapheme is almost perfectly one-to-one in Dutch, the question arises whether it is indeed phonological similarity that drives the attested analogical effects in the experiment, or orthographic similarity. The results show that phonologically based analogy is a good predictor of the reading times. Importantly, the words that are phonologically similar may differ in the spelling of their final obstruents (*b* versus *p*, *d* versus *t*, and *g* versus *ch*). That is, words are affected by words that end in similar sounds but not necessarily in the same graphemes. Phonological similarity drives at least partly the analogical effects in reading.

There may be two different sources for the analogical effects in reading documented in this paper. First, they may be due to on-line processes. The reading of a verb form activates the representation of this verb form in the speaker's lexicon, if present, as well as the representations for its stem, the within-paradigm neighbors, and the inter-paradigmatic neighbors. The activated words may support the given spelling of the form, which may shorten the reading times. Second, the documented effects may be due to the possible storage of incorrect forms, which result from analogy in production. Using the search engine *Altavista* we conducted a search on the internet of the correct and incorrect forms used in Experiments IV and V. This showed that the lexically incongruent verbs are spelled with an incorrect allomorph much more frequently than the lexically congruent verbs. The simple past forms of the lexically incongruent verbs in Experiment IV were spelled with an incorrect allomorph in 13% of cases, and the congruent forms in less than 1% of cases. Similarly, the lexically incongruent past participles in Experiment V were spelled with an incorrect allomorph in 16% of cases, and the congruent past participles in only 5% of cases. If a speaker stores nearly all frequently occurring word forms, then especially the incorrect forms supported by analogy may leave traces. Speakers may consequently read these forms faster

than the infrequent incorrect forms which are not supported by analogy and which they have not stored. Further research is necessary in order to determine the relative contributions of on-line processes and storage to the analogical effects in reading.

In conclusion, previous studies (e.g., Skousen, 1989; Krott, 2001; Krott, Baayen & Schreuder, 2001; Ernestus & Baayen 2001, 2003) have shown that the production of existing words and the creation of new morphologically complex forms in isolation are affected by the properties of semantic, phonological, morphological, and orthographical neighbors. Our results show that also reading morphologically complex words in meaningful contexts is affected by lexical neighbors. These analogical effects are both intra- and interparadigmatic in nature.

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Appendix

Materials for Experiment I

t-supporting verbs:	klapt, stept, schopt, schimpt, danst, grist, blust, krast.
d-supporting verbs:	plaagt, spuugt, vlagt, turft, bloost, loost, raast, peinst.

Materials for Experiment II

Neutral verbs:	zuigt, weegt, liegt, buigt, vliegt, zwijgt, stijgt, bergt, geeft, snuift, wrijft, schuift, drijft, graaft, sterft, prijst, leest, blaast, pluist, kiest.
d-supporting verbs:	zaagt, pleegt, voegt, deugt, klaagt, droogt, legt, zorgt, leeft, zweeft, streeft, proeft, wuift, beeft, durft, reist, vreest, huist, graast, raast.

Materials for Experiment III

t-supporting verbs:	stapt, knoopt, klopt, sleept, gaapt, stopt, hoopt, kraakt, merkt, raakt, kweekt, smeekt, bluft, sloft, straft, blaft, sist, krast, lost, mist.
Neutral verbs:	zuigt, weegt, liegt, buigt, vliegt, zwijgt, stijgt, bergt, geeft, snuift, wrijft, schuift, drijft, graaft, sterft, prijst, leest, blaast, pluist, kiest.
d-supporting verbs:	zaagt, pleegt, voegt, deugt, klaagt, droogt, legt, zorgt, leeft, zweeft, streeft, proeft, wuift, beeft, durft. reist, vreest, huist, graast, raast.

Materials for Experiment IV

Lexically congruent verbs:	gedopt, geklapt, geschimpt, gehapt, gekrast, gegrist, geslist, gesist, gespuugd, gevlagd, gedeugd, geturfd, geloosd, geraasd, gebloosd, gegrijnsd.
Lexically incongruent verbs:	gekucht, gepocht, gejuicht, gesurft, gekruist, geëist, gekrijst,

geloenst, gebonsd, geglansd, geplensd, geplonsd, gedubd, gekrabd, geschrobd, getobd.

Materials for Experiment V

Lexically congruent verbs:	dopte, stepte, schimpte, raapte, surfte, kraste, wiegde, deugde, spuugde, zeefde, peinsde, grijnsde, raasde, smoesde.
Lexically incongruent verbs:	juichte, kuchte, pochte, surfte, kruiste, loenste, krijste, dubde, krabde, schrobde, tobde, glansde, grensde, bonsde.

Table 1: The forms of regular Dutch verbs

	t-supporting verbs	*d*-supporting verbs
1st, 2nd person singular present tense	stem	stem
2nd, 3rd person singular present tense	stem + *t* / [t]	stem + *t* / [t]
plural present tense, infinitive	stem + *en* / [ən]	stem + *en* / [ən]
singular simple past	stem + *te* / [tə]	stem + *de* / [də]
plural simple past	stem + *ten* / [tən]	stem + *den* / [dən]
present participle	stem + *ende* / [əndə]	stem + *ende* / [əndə]
past participle	*ge* + stem + *t* / [t]	*ge* + stem + *d* / [t]
attributively used past participle	*ge* + stem + *te* / [tə]	*ge* + stem + *de* / [də]

Table 2: Two examples: *krassen* 'to scratch' and *lozen* 'to drain'

	t-supporting verbs	*d*-supporting verbs
1st, 2nd person singular present tense	*kras* [krɑs]	*loos* [los]
2nd, 3rd person singular present tense	*krast* [krɑst]	*loost* [lost]
plural present tense, infinitive	*krassen* [krɑsən]	*lozen* [lozən]
singular simple past	*kraste* [krɑstə]	*loosde* [lozdə]
plural simple past	*krasten* [krɑstən]	*loosden* [lozdən]
present participle	*krassende* [krɑsəndə]	*lozende* [lozəndə]
past participle	*gekrast* [ɣəkrɑst]	*geloosd* [ɣəlost]
attributively used past participle	*gekraste* [ɣəkrɑstə]	*geloosde* [ɣəlozdə]

Table 3: Analogical gangs defined in terms of the segments of their final rhymes, and their support for voiced obstruents before vowel-initial suffixes (Ernestus & Baayen, 2003). The segments between the first pair of brackets present the possible vowels of the final rhymes, while the segments between the second pair present the possible pre-final consonants. A "-" represents the possibility of the absence of a pre-final consonant. The final pair of brackets enclose the possible final obstruents.

Analogical neighborhood gangs	Support for voicing
1. {ɛi, ɑu, œy, aː, eː, oː, øː, i, u}{-, j, l, m, n, r} {p}	.000
2. {ɛi, ɑu, œy, aː, eː, oː, øː, i, u}{-, j, l, m, n, r} {t}	.372
3. {ɛi, ɑu, œy, aː, eː, oː, øː, i, u}{-, j, l, m, n, r} {s}	.755
4. {ɛi, ɑu, œy, aː, eː, oː, øː, i, u, ɑ, ɛ, ɪ, ɔ, ʏ, y}{f, k, p, s, t, x}{p, t, s}	.019
5. {ɑ, ɛ, ɪ, ɔ, ʏ, y}{-, m, r} {p, t, s}	.135
6. {ɑ, ɛ, ɪ, ɔ, ʏ, y}{l, n} {p, t, s}	.357
7. {ɛi, ɑu, aː, eː, oː, øː, y}{-, j, l, r, m, n}{f, x}	.992
8. {i, u}{-, m} {f}	.778
9. {ɑ, ɛ, ɪ, ɔ, ʏ}{-, m} {f}	.081
10. {ɑ, ɛ, ɪ, ɔ, ʏ, i, u}{l, r} {f}	.775
11. {ɑ, ɛ, ɪ, ɔ, ʏ, i, u}{-, j, l, r, m, n} {x}	.953

Table 4: The average reading times in milliseconds for the third person singular present tense verb forms with correct *t* or incorrect *d*, and for the two directly following words in Experiment I.

		Verb form	Following word	2^{nd} following word
d-supporting verbs	correct *t*	371	357	372
	incorrect *d*	383	385	371
	incorrect - correct	12	28	1
t-supporting verbs	correct *t*	387	365	374
	incorrect *d*	446	398	381
	incorrect - correct	59	33	7

Table 5: The main effects and interactions that are significant in either the overall participant (Df = 58) or the overall item (Df = 14) analysis of variance of the reading time data of Experiment I.

Effect	Participant		Item	
	F-value	p-value	F-value	p-value
Speed	90.52	$< .01$	261.71	$< .01$
Verb Type	7.48	$< .01$	1.04	$> .10$
Correctness	27.84	$< .01$	13.54	$< .01$
Position	3.90	.05	9.50	$< .01$
Speed * Correctness	12.23	$< .01$	6.73	.02
Speed * Position	11.07	$< .01$	22.40	$< .01$
Verb type * Correctness	3.86	.05	1.29	$> .10$
Verb Type * Position	4.00	.05	3.33	.09
Verb Type * Correctness * Position	4.17	.05	14.0	.09

Table 6: The frequencies with which the final rhymes of the *d*-supporting verbs and the *t*-supporting verbs in Experiment I are followed by word-final *t* and *d*, according to CELEX.

Verb type	Grapheme sequence	Frequency with *t*	Frequency with *d*
d-supporting verbs	long vowel + *g*	27182	22717
	short vowel + *g*	36577	37393
	long vowel + *s*	141293	6404
	ns	23996	427
	rf	1929	775
t-supporting verbs	short vowel + *p*	12763	0
	mp	1736	0
	short vowel + *s*	91403	0

Table 7: The average reading times in milliseconds for third person singular present tense forms correctly spelled with *t* or incorrectly spelled with *d*, and for the two directly following words in Experiment II.

		verb form	following word	2^{nd} following word
d-supporting verbs	correct	326	324	320
	incorrect	338	326	326
	incorrect - correct	12	2	6
neutral verbs	correct	331	315	337
	incorrect	356	352	341
	incorrect - correct	25	37	4

Table 8: The main effects and interactions that are significant in either the overall participant (Df = 34) or the overall item (Df = 38) analysis of variance of the reading time data of Experiment II.

Effect	Participant		Item	
	F-value	p-value	F-value	p-value
Speed	52.48	$< .01$	670.03	$< .01$
Verb type	6.33	.02	.50	$> .10$
Correctness	21.48	$< .01$	12.88	$< .01$
Speed * Position	12.72	$< .01$	23.07	$< .01$
Verb type * Correctness	12.70	$< .01$	4.88	.03

Table 9: The average reading times in milliseconds for the third person singular present tense forms correctly spelled with *t* or incorrectly spelled with *d*, and for the two following words in Experiment III.

		verb form	following word	2^{nd} following word
d-supporting verbs	correct	354	337	347
	incorrect	375	345	347
	incorrect - correct	21	8	0
neutral verbs	correct	356	330	344
	incorrect	370	360	358
	incorrect - correct	14	30	14
t-supporting verbs	correct	352	334	351
	incorrect	401	387	382
	incorrect - correct	49	53	31

Table 10: The main effects and interactions that are significant in either the overall participant (Df = 37) or the overall item (Df = 38) analysis of variance of the reading time data of Experiment III.

Effect	Participant		Item	
	F-value	p-value	F-value	p-value
Speed	58.13	$< .01$	1878.12	$< .01$
Verb type	15.73	$< .01$	.91	$> .10$
Correctness	62.58	$< .01$	18.21	$< .01$
Positie	2.98	.06	8.48	$< .01$
Speed * Position	4.94	.01	19.96	$< .01$
Verb type * Correctness	14.64	$< .01$	2.87	.07
Correctness * Position	2.95	.07	19.96	.02
Speed * Correctness * Position	4.78	.1	7.70	$< .01$

Table 11: The average reading times in milliseconds for simple pasts spelled with the correct allomorph or the incorrect allomorph, and for the two following words in Experiment IV.

		verb form	following word	2^{nd} following word
Lexically congruent verb	correct	356	364	348
	incorrect	377	405	362
	incorrect - correct	21	41	14
Lexically incongruent verb	correct	358	341	333
	incorrect	345	362	349
	incorrect - correct	-13	21	16

Table 12: The main effects and interactions that are significant in either the overall participant (Df = 50) or the overall item (Df = 26) analysis of variance of the reading time data of Experiment IV.

Effect	Participant		Item	
	F-value	p-value	F-value	p-value
Speed	98.38	$< .01$	583.37	$< .01$
Verb type	25.80	$< .01$	1.74	$> .10$
Correctness	8.19	$< .01$	11.18	$< .01$
Verb type * Correctness	6.20	.02	4.43	.05
Correctness * Position	3.55	.07	5.92	.02

Table 13: The average reading times in milliseconds for past participles spelled with the correct allomorph or the incorrect allomorph, and for the two following words in Experiment V.

	spelling	verb form	following word	2^{nd} following word
Lexically congruent verb	correct	388	386	324
	incorrect	386	403	329
	incorrect - correct	-2	17	5
Lexically incongruent verb	correct	392	361	318
	incorrect	373	365	320
	incorrect - correct	-19	4	2

Table 14: The main effects and interactions that are significant in either the overall participant (Df = 80) or the overall item (Df = 30) analysis of variance of the reading time data of Experiment V.

Effect	Participant		Item	
	F-value	p-value	F-value	p-value
Speed	140.03	$< .01$	681.88	$< .01$
Verb type	20.98	$< .01$	1.16	$> .10$
Speed * Position	14.23	$< .01$	33.74	$< .01$
Verb type * Correctness	4.90	.03	1.25	$> .10$
Verb type * Position	13.24	$< .01$	4.12	.05
Correctness * Position	3.31	.07	11.18	$< .01$
Correctness * Position * Speed	2.39	$> .10$	5.25	.03