ELSEVIER

Acta Psychologica 105 (2000) 31–56

acta psychologica

www.elsevier.com/locate/actpsy

Sentence reading: Do we make use of orthographic cues in homophones?

Marc Brysbaert [a,*], Stefan Grondelaers [b], Elie Ratinckx [a]

[a] *Department of Experimental Psychology, Ghent University, Henri Dunantlaan 2, B-9000 Ghent, Belgium*

[b] *Katholieke Universiteit Leuven, Leuven, Belgium*

Received 21 September 1999; received in revised form 8 May 2000; accepted 16 May 2000

Abstract

Starting from the finding that currently phonological models of visual word processing predominate, we examined what happened when important morphological information is disclosed in the orthography but not in the phonology. To do so, we made use of a peculiarity in Dutch. In this language, some forms of the present and the past tense of verbs are homophones or homographs. This allowed us to look at the power of orthographic and phonological cues to derive the tense of the verb. Two experiments showed that orthographic cues alone suffice to recover the tense of the verb, and that this recovery does not take more time than tense recovery on the basis of a combination of orthographic and phonological cues. On the basis of these results, we conclude that orthographic cues in homophones are very efficient during silent reading. Our findings, however, do not allow us to conclude whether this is due to a direct route from orthography to meaning, or to a specialised, morpho-syntactic back-up strategy elicited by certain sequences of letters. © 2000 Elsevier Science B.V. All rights reserved.

1. Introduction

Theories of visual word processing and sentence reading have undergone a major change in the last decade. Ten years ago, theories of reading in which phonology

* Corresponding author. Tel.: +32-9-264-6408; fax: +32-9-264-6496.

E-mail address: marc.brysbaert@rug.ac.be (M. Brysbaert).

PII: S0001-6918(00)00047-0

played a major role were regarded with considerable scepticism (e.g. Forster, 1990; Humphreys & Evett, 1985; Patterson & Coltheart, 1987). Today, an increasing number of articles are published in which the idea is defended that visual word recognition and sentence reading rely almost entirely on a phonological code (e.g., Frost, 1998; Lukatela & Turvey, 1994; Van Orden, 1991). This shift from orthographic to phonological processing mirrors a previous shift from phonological to orthographic processing, because at the beginning of the so-called cognitive revolution (Neisser, 1967), many researchers thought that implicit speech was an essential factor in visual perception and memory. In the early 1970s this led, for instance, to a lively controversy about the presence of syllable length effects in the perception of visually presented Arabic numerals (e.g., Pynte, 1974). The origin of the current return to the phonological mediation hypothesis, are the hundreds of experiments in which phonological effects were found even though the task did not require the printed words to be named.

However, before we discuss the experiments that resulted in the current appeal of strong phonological models of visual word recognition, it is important to draw a distinction between what is usually called assembled phonology and addressed phonology (Patterson & Coltheart, 1987). The best way to do this is to start from Coltheart's (1978) dual-route model of visual word naming, that paved the way for the orthographically dominated models. According to Coltheart, visually presented words can be named in two ways. Either they first activate an entry in the orthographic input lexicon, from which the correct phonology is addressed, or the phonology is assembled directly from the visual input by means of grapheme–phoneme conversion rules. The distinction between assembled and addressed phonology offered an elegant explanation for a number of phenomena that at the time could not easily be integrated within a single route. One of these phenomena was that humans are able to name both non-words, which by definition do not have a representation in the orthographic input lexicon, and irregular words, which cannot be named by applying the normal grapheme-to-phoneme rules (e.g. the word *pint* in English). By assuming that the former are named through the direct grapheme–phoneme route and the latter with the use of indirect lexical look-up, the model nicely accounted for those findings and could explain the existence of dyslexic patients who have problems naming non-words but not irregular words (phonological dyslexics), and dyslexic patients who can readily name non-words but who regularise irregular words (surface dyslexics).

Very few researchers, even those defending the strongest orthographic models of visual word recognition, deny the importance of addressed phonology in reading, because there is abundant evidence that phonological codes play an important role in text comprehension. Many of us have the impression that we use an inner voice, when we are reading silently (especially when the text is difficult), and historical documents suggest that silent reading is a very recent phenomenon: Up to 100 years ago, reading aloud was the default option. Apparently, our memory relies more on phonological than on orthographic codes when information needs to be retained. In the experimental literature, there is a great deal of evidence that persons required to retain small amounts of material even for a short period of time rely heavily on some form of phonological code (e.g., Levy, 1977; Slowiaczek & Clifton, 1980). This has been the basis of the hypothesised phonological loop in the working memory model (Baddeley, 1986), and studies with patients whose word span was seriously reduced because of brain damage, have indicated that these patients have difficulties with text comprehension when the sentences are long and complex (e.g., Baddeley, Vallar, & Wilson, 1987; Caspari, Parkinson, LaPointe, & Katz, 1998). Other evidence that phonology is pivotal for text comprehension during silent reading comes from the visual tongue-twister effect (McCutchen & Perfetti, 1982; McCutchen, Dibble, & Blount, 1994). Readers have more difficulties reading and remembering sentences that include repeated initial consonants (e.g., *the purpose of the play was to please the brave prince*) than control sentences. The effect is not limited to English but has also been documented for Chinese (Zhang & Perfetti, 1993), a language which due to its ideographic writing system seems less suited for the use of phonology.

It should be noted, however, that the role of phonology in text comprehension is a different issue than the role of phonology in visual word identification, because the former can easily be based on addressed phonology. Also in the strong phonological models of visual word recognition, a distinction is drawn between the role of phonology in the word identification process and the role of phonology in text understanding. As Frost (1998) indicated, it is quite likely that the prelexical, assembled phonology is less detailed than the postlexical, addressed phonology, because most of the time not all phonemic information is needed to identify a word (a similar claim was made by Nas, 1983). Therefore, the issue of the use of phonological codes in text comprehension is orthogonal to the issue of the use of phonological codes in visual word identification, and many authors who reject a pivotal role of phonology in reading, reject the latter but not the former.

The first important empirical demonstration that assembled phonology plays a role in visual word identification was reported by Rubenstein, Lewis and Rubenstein (1971). They showed that visually presented non-words that sounded like a word (e.g. *brane*) took longer to reject in a lexical decision task than control non-words that did not sound like a word (e.g. *rolt*). This so-called pseudohomophone effect in lexical decision remained for a long time the hallmark of phonological coding in visual word processing, but lost much of its attraction after Van Orden's (1987) devastating analysis. Van Orden pointed to two problems with the interpretation of the effect. First, the pseudohomophone effect in lexical decision may tell us nothing about how real words are identified, because it is observed on *no*-trials, which are slower than *yes*-trials. Second, the lexicality judgement may be based on stimulus familiarity (is the stimulus sufficiently familiar to be labelled a word?), an assessment that does not need to be involved in the word identification process per se (e.g., Besner & McCann, 1987).

Baron (1973) introduced a second paradigm to examine the issue of phonological coding in silent reading. He asked participants to read short phrases and judge whether each phrase made sense. Some of the incorrect phrases included a homophonic word that made the sentence sound correct, e.g. *tie the not*. Although participants were not slower to reject such sound-correct sentences than sentences which both looked and sounded wrong, they did make significantly more false-positive errors on the sound-correct sentences. Subsequent research (see Patterson & Coltheart, 1987, pp. 437–438 for a review) has extended the finding to pseudohomophones (i.e., non-words that make the sentence sound correct). This extension is important because it suggests that words do not have to be identified before the phonology can be addressed, but that the phonology is being assembled before word identification occurs. A paradigm closely related to phrase evaluation is proofreading. Here too, participants miss significantly more errors that preserve the phonology than errors that violate the phonology. The effect is obtained both with homophones (e.g., Daneman & Stainton, 1991) and pseudohomophones (e.g., Van Orden, 1991), and it is present from the first year of reading onwards (Bosman & de Groot, 1996).

Pollatsek, Lesch, Morris and Rayner (1992) provided more direct evidence for the use of phonological codes during text reading by using eye movement contingent display changes. They showed that during reading observers process a foveal word faster when at the time of the previous fixation a homophonic stimulus was presented in the parafovea rather than a non-homophonic control. Thus, during silent reading, the target word *rains* was processed faster when on the previous fixation the word *reins* had been presented in the parafovea than the orthographic control *ruins* (see also Lee, Rayner, & Pollatsek, 1999; Rayner, Sereno, Lesch, & Pollatsek, 1995).

Phonological effects can also readily be observed in semantic tasks with isolated words. For instance, participants often erroneously classify homophones as exemplars of a semantic category (Van Orden, 1987), at least when the categories are not too broad (Van Orden, Holden, Podgornik, & Aitchison, 1999). Thus, in a rather high percentage of cases, participants indicate that a *rows* is a flower, but not that it is a living thing (vs. a man-made object). The effect is more pronounced when stimulus presentation duration is limited (Van Orden, 1987). According to Van Orden, this is because as soon as a word is identified on the basis of its phonology, a spelling check is done to inhibit the wrong entries. If stimulus presentation is too short, the spelling check cannot be used. Van Orden (1987) concluded this from the finding that the orthographic similarity between the target and the homophone had a large effect on the number of errors when presentation time was unlimited, whereas it made no difference when stimulus presentation was tachistoscopic. A related finding was reported by Luo, Johnson and Gallo (1998). They found that participants needed more time and made more errors when they had to indicate that the word pair *lion–bare* was not semantically related than when they had to indicate that the non-homophonic control pair *lion–bean* was not semantically related. Interestingly, this time the effect was equally strong with unlimited vision as with limited vision (250 ms), and was found both with homophones and pseudohomophones (e.g. *table–chare* vs. *table–chark*). Other research has indicated that homophone errors in semantic judgement tasks are not limited to alphabetical languages but can also be observed in logographic languages like Chinese (e.g., Perfetti & Zhang, 1995; Xu, Pollatsek, & Potter, 1999), which for a long time were thought not to involve phonology in word identification.

Also related to the issue of semantic processing, it has been shown that target words (e.g., *frog*) are not only primed by associated words (e.g., *toad*) but also by homophones of the associated words (*towed*) and by pseudohomophones (*tode*), at least when presentation time of the prime is short (50 ms; Lesch & Pollatsek, 1993; Lukatela & Turvey, 1994). If presentation time is longer, targets can no longer be primed by homophones (Fleming, 1993; Lukatela & Turvey, 1994), presumably because of the orthographic inhibition due to the spelling check (see above).

In parallel with the line of research showing phonological effects in semantic tasks with visual words, there was another line of research showing phonological effects in the identification of visual words per se. This line of research started with the work of Humphreys, Evett and Taylor (1982), who used the masked priming paradigm. In this paradigm, a target word is preceded by a prime that is presented too briefly to be identified, but still has effect on the subsequent processing of the target word (i.e., Evett and Humphreys (1981) had shown that target identification improved the more letters prime and target shared). One of the questions Humphreys et al. asked was whether a target word would be identified more easily when it was preceded by a homophonic prime than when it was preceded by a graphemic control that shared the same number of letters with the target word but not the same number of sounds. They indeed found such a phonological priming effect (i.e. the target word *HAIR* was more often identified when it was preceded by the homophone *hare* than when it was preceded by the graphemic control *hall*). The effect was, however, not present for non-word primes, leading Humphreys et al. to conclude that phonology in word recognition played a role only after the word had made access to the visual input lexicon. This lexical interpretation was later called into question by Perfetti and Bell (1991) who showed that the null-effect was due to the short presentation time of the prime and that the effect could be obtained with non-word primes (e.g., *creap–CREEP* vs. *crelp–CREEP*), provided that the prime was presented for longer than 35 ms (see Grainger & Ferrand (1996) and Van Cauteren (1997) for similar results in French and Dutch). In addition, Brysbaert, Van Dyck and Van de Poel (1999) reported that the effect can be extended to a cross-language situation. If bilinguals have to identify a target word of their second language, they perform better when the target is preceded by a prime which according to the letter-sound correspondences of the mother tongue is a pseudohomophone of the target. Thus, performance of Dutch–French bilinguals is better for the homophonic pair *soer–SOURD* than for the control pair *siard–SOURD*. Perfetti, Bell and Delaney (1988) obtained similar results with a backward masking paradigm, in which the masked non-word did not precede the target but followed it (an effect replicated in Hebrew by Gronau & Frost, 1997). Furthermore, the effect does not seem to depend on the frequency of the target words, the regularity of the target words, or the usefulness of the phonological information in the prime for the task as a whole (Perfetti & Bell, 1991; Xu & Perfetti, 1999).

Although the abundance of empirical evidence in favour of phonological effects in visual word processing has been a critical factor in the current swing from orthographically dominated models to phonologically dominated models of visual word recognition, the appeal of the strong phonological models would not be as strong if at the same time there had not been a progress in our understanding of the underlying processes. As we have indicated, one of the arguments that made Coltheart

(1978) develop his well-known dual-route model of visual word naming, was the naming of both non-words and irregular words. Only after the development of computational, distributed models, it was possible to imagine a single non-lexical system that could convert both types of graphemic input into the correct phonemic output (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). In addition, these models could simulate other important empirical findings that at first sight seemed to require two independent routes for their explanation, such as the interaction between word frequency and word regularity/consistency and the different types of dyslexia (see in particular Plaut et al., 1996).

The plausibility of a non-lexical grapheme–phoneme conversion system even for a highly irregular language as English, and the impressive amount of empirical evidence in favour of phonological coding, made some researchers conclude that there was no need for an orthographic route in visual word recognition any more. Van Orden, Pennington and Stone (1990), for instance, argued that if the letter–sound conversions are not based on a set of rules, there is no positive evidence left for direct orthographic lexical access. All evidence for such access then is based on null-effects (i.e., failures to find phonological influences). Indeed, many claims for an orthographic route have been made after a failure to observe or to repeat a phonological effect (e.g., Brysbaert & Praet, 1992; Chen, d'Arcais, & Cheung, 1995; Davis, Castles, & Iakovidis, 1998; Taft & van Graan, 1998). Also, some findings that at first sight seemed to argue in favour of an independent orthographic route, later turned out to be misinterpreted. A typical example is Nas (1983). In Experiment 1, Nas looked at how Dutch–English bilinguals process Dutch words (e.g. *lood*) in an English lexical decision task. He found that the Dutch words took considerably longer to reject than control non-words, despite the fact that English grapheme–phoneme conversion rules would have resulted in non-words in both languages. On the basis of this finding, Nas (1983) concluded that phonological information was not the only information on which the lexical decision was based. Subsequent research by Brysbaert et al. (1999), however, indicated that when bilinguals see a word in one of their languages, the grapheme–phoneme correspondences of both mastered languages are activated, so that Nas's finding cannot be considered as evidence against a strong phonological view of visual word recognition.

Other evidence that has been re-examined given the current evidence of ubiquitous phonological effects in visual word processing, is the phonological processing in dyslexic patients who apparently are no longer able to use the non-lexical letter-to-sound conversion system (because they cannot name non-words). Katz and Lanzoni (1992) investigated a deep dyslexic patient whose performance in oral reading and other tasks suggested that the person was poor at activating the phonology of both words and non-words from printed stimuli. For instance, given the stimuli *bribe–tribe* and *couch–touch*, he could not decide which pair rhymed and which did not. However, when asked to do a lexical decision task (are both stimuli words or not), the patient showed the same phonological effects as normals (i.e., faster response latencies on *bribe–tribe* than on control trials, and slower on *couch–touch* than on control trials). Subsequent research with other patients has confirmed the finding that patients who are no longer able to use phonology explicitly, still show implicit phonological effects, suggesting that the phonological code in visual word recognition is not the same as the code used for the pronunciation of words (Buchanan, Hildebrandt, & MacKinnon, 1996; Frost, 1998). It may be recalled that the inability of some dyslexic patients to name non-words was considered by Coltheart (1978) as some of the most convincing evidence in favour of the dual-route model.

Frost (1998) added several other arguments against the existence of an independent orthographic pathway in visual word recognition. The most important are: (i) the assumption one has to make that addressed phonology is easier to activate from print than assembled phonology (i.e., that phonology is immediately available after access to the orthographic input lexicon), and (ii) the assumption that during reading acquisition, an additional mapping is made from orthography to semantic meaning, besides the mapping that is made from orthography to phonology (because the first thing children learn is how the visual characters symbolise auditory words). Or as Frost (1998, p. 74) put it: "... Because, in reading acquisition, lexical structure initially connects orthography to phonology and not to meaning, the burden of proof lies on those who argue that a structural change emerges later on with skilled performance and that there is direct access from orthography to meaning, thus bypassing phonological structure. Direct evidence of such a structural change should be provided."

So, it may be worthwhile to examine what positive evidence researchers still have in favour of direct access from orthography to meaning, *in addition to* a phonologically mediated access. Usually, this evidence consists of effects due to orthographic similarity that cannot be reduced to phonological overlap. For instance, many authors point to the fact that the percentage of homophonic errors in proofreading and semantic judgement tasks, although higher than that of control stimuli, rarely exceeds 20%, unless presentation time is artificially short. However, this argument is only valid for models which assume that the orthographic information is completely lost after the phonological conversion. As argued by Frost (1998, pp. 90, 91), none of the current strong phonological models makes this claim. They either allow for a kind of a spelling check, or the orthographic input is believed to have implications on the phonological representation that is activated (e.g., if the phonological representation is not the full-blown pronunciation of the word, it may be that the phonological representation of *rose* is not exactly the same as that of *rows*; also if the phonological representation is conceived in continuous interaction with the orthographic input, the coherence loop may not be the same for *rose* as for *rows*; Van Orden & Goldinger, 1994).

On the other hand, there is some evidence for a genuine contribution of orthography to visual word recognition that at present cannot be reduced to phonology. Ferrand and Grainger (1993, 1994; see also Brysbaert et al., 1999) made use of the fact that the French language has fairly unrestricted phoneme–grapheme correspondences (so that a sound can be represented by different sequences of letters) and transparent grapheme–phoneme correspondences (so that the pronunciation of a written stimulus can easily be assembled). Because of these characteristics, the same sounds in French can be represented by quite different sequences of letters that all have the same, unambiguous pronunciation. This allowed Ferrand and Grainger to construct two different types of homophonic primes for their target words: one type consisting of non-words that had a large orthographic overlap with the target (e.g., *fain–FAIM*), and a type of non-words with a small orthographic overlap (e.g., *fint–FAIM*). In addition, they used a third type of primes that were not pseudohomophones of the targets, but that had a large orthographic overlap (*faic–FAIM*). By comparing the priming effects of *fain* and *faic*, it was possible to get an idea of the contribution of phonology to word recognition, and by comparing the priming effects of *fain* and *fint*, the orthographic contribution could be assessed. Ferrand and Grainger obtained independent effects of orthography and phonology, and in addition found that both followed a different time course. The orthographic contribution was maximal around 30 ms and then rapidly dropped, whereas the phonological contribution took longer to start and peaked around 60 ms. Ferrand and Grainger interpreted this finding as evidence for an independent contribution of orthography and phonology to word identification, with the orthographic pathway being activated more rapidly (see also Lee et al., 1999; Xu et al., 1999). As far as we are aware, this is the only positive evidence left for a distinct connection between orthography and semantics.

Given the strong phonological claims recently made and the scarcity of direct positive evidence for an independent orthographic pathway in visual word recognition, it becomes interesting to examine how the reading system deals with important verbal information that is not (or at least very weakly) represented in the phonological code. After all, many writing systems include important morphological cues that are not present in the phonology. A typical example is French, where the difference between many singulars and plurals cannot be heard but is nevertheless incorporated in the spelling (e.g., the expression *il joue* [he plays] is pronounced the same as *ils jouent* [they play]). Another example is Dutch, where for a number of verbs, the difference between the present and the past tense is captured by a pair of homophones (e.g., *zij betwisten* [they dispute] vs. *zij betwistten* [they disputed]). Does the reading system have problems processing such expressions? Several predictions are possible. On the basis of the phrase evaluation and the proofreading studies, one would expect that quite often the tense information disclosed by such homophones will be overlooked, certainly when the context heavily constrains the interpretation (Rayner, Pollatsek, & Binder, 1998; Van Orden et al., 1999). Such a finding would certainly be in line with the phonological claims. On the other hand, it is also possible that the information is not overlooked, but requires extra processing time, for instance because a spelling check must be done. Finally, it is possible that the processing of homophonic verb forms does not differ from the processing of non-homophonic verb forms. This would be in line with models that incorporate an orthographic route to meaning, but also with phonological models that accept early orthographic constraints on the extracted phonology (cf. Frost, 1998). Of course, in that case, these constraints would have to be incorporated in a viable model.

Apart from the theoretical importance of the results, there are also practical implications. In the Dutch speaking community, for instance, there have been recurrent claims to "simplify" the spelling, in particular with respect to the homophonic verb forms. The spellings of these forms appear to be the most difficult to learn (Sandra, Frisson, & Daems, 1999), and even adults are quite susceptible to making errors against them (giving them the status of "the tragedy of the Dutch spelling"; van der Velde, 1956). These forms have been maintained on the basis of morphological consistency. For instance, the present, third person singular form of a verb is formed by the rule *root* + *t*, irrespective of whether the ending *t* can be heard or not; compare *hij leef-t* [he lives] and *hij vind-t* [he finds]. [1] However, if it turned out that such orthographic information is not used, or even causes reading problems, then the argument of morphological informativeness vanishes.

From a methodological point of view, the sole existence of homophonic and non-homophonic forms is not exceedingly interesting, because it only allows one to look for phonological effects (a comparison of orthographic plus phonological information vs. orthographic information alone). Any orthographic effect then comes down to a null-effect (i.e., the difficulty of finding a difference between both situations). However, the situation in Dutch is more interesting than this, because there are also a number of verbs for which the present and the past tenses are homographs (e.g., *zij beknotten* [they curtail] vs. *zij beknotten* [they curtailed]). A comparison of these verbs with the homophonic verbs makes it possible to examine true orthographic effects (a comparison of no information vs. orthographic information).

Thus far, only van Heuven (1978) has used the above three types of verb forms to find out whether readers take profit from the tense information revealed by homophonic verb forms. In Dutch, the plural forms of regular verbs are formed by adding *-en* to the root in the present tense and *-den* or *-ten* (depending of the last letter of the root) in the past tense, except when the root already ends on *-dd* or *-tt* (in which case the inflection *-en* has to be added both in present and in past). As a consequence of these rules, the plural forms of the present and the past tense are (i) heterophonic when the root does not end on *-d* or *-t*, (ii) homophonic when the root ends on *-d* or *-t*, and (iii) homographic when the root ends on *-dd* or *-tt*. This allowed van Heuven to construct the following sextet of sentences:

(1a) Terwijl de moeders *harken* in de tuin, *zitten* de vaders in hun luie stoel. [While the mothers *are raking* in the garden, the fathers *are sitting* in their chair.]
(1b) Terwijl de moeders *harkten* in de tuin, *zaten* de vaders in hun luie stoel. [While the mothers *were raking* in the garden, the fathers *were sitting* in their chair.]
(2a) Terwijl de moeders *wieden* in de tuin, *zitten* de vaders in hun luie stoel. [While the mothers *are weeding* in the garden, the fathers *are sitting* in their chair.]
(2b) Terwijl de moeders *wiedden* in de tuin, *zaten* de vaders in hun luie stoel. [While the mothers *were weeding* in the garden, the fathers *were sitting* in their chair.]

[1] Actually the situation is slightly more complicated because the ending *t* is not added when the root ends on a *t*; e.g., **hij groett* [*he greets*].

(3a) Terwijl de moeders *spitten* in de tuin, *zitten* de vaders in hun luie stoel. [While the mothers *are turning over soil* in the garden, the fathers *are sitting* in their chair.]

(3b) Terwijl de moeders *spitten* in de tuin, *zaten* de vaders in hun luie stoel. [While the mothers *were turning over soil* in the garden, the fathers *were sitting* in their chair.]

In sentence pair (1a,b) the tense of the verb of the subordinate clause is indicated by a phonemic as well as an orthographic cue (i.e., *harken* both looks and sounds different from *harkten*); in sentence pair (2a,b) only an orthographic cue is present (because *wieden* and *wiedden* sound the same); and in sentence pair (3a,b) no cue is present to recover the tense of the verb in the subordinate clause. In all cases, the verb of the main clause (which makes a phonemic and orthographic distinction between present and past) removes the ambiguity that might be introduced by the verb of the subordinate clause. English equivalents of the sentences do not exist (because voiced consonants do not become voiceless at the end of a word, as in Dutch, so that *bend* and *bent* are not really pronounced the same), but a close approximation is given by:

(4a) When they tap the toy, it starts to play.
(4b) When they tapped the toy, it started to play.
(5a) *When they bend the toy, it starts to play.
(5b) *When they bent the toy, it started to play.
(6a) When they hit the toy, it starts to play.
(6b) When they hit the toy, it started to play.

van Heuven (1978, Experiment 8) found that tense recovery was hardest for sentence pair (3a,b), followed by (2a,b), and by (1a,b), exactly as predicted by models of visual word recognition that depend heavily on phonology. Unfortunately, van Heuven used a design that had very limited power (he used only four sextets, so that the findings were not significant in the F2 analysis) and he only looked at total sentence reading time. In addition, the frequency and the length of the different verbs were not controlled, raising the possibility that the effects were due to one of these variables. Therefore, we decided to set up a replication of van Heuven (1978) to investigate the issue properly.

2. Experiment 1

2.1. Method

Participants. Forty-two first-year students from the University of Leuven took part in the experiment. All were native Dutch speakers with normal or corrected-to-normal vision. None of the participants knew about the research hypothesis.

Stimulus materials. The test sentences consisted of 18 sextets of sentences (see Appendix A) either borrowed from van Heuven (1978) or newly built for the present study. Each sextet consisted of a pair of heterophonic verb forms (*harken*, *harkten*), a pair of homophonic verb forms (*wieden*, *wiedden*), and a pair of homographic verb forms (*spitten*, *spitten*). Care was taken to make the different pairs of verb forms (which was the only point at which the sentences differed) as equal as possible within a sextet, either by using synonyms or, if this was not possible, by taking verbs closely related in the semantic space (cf. the verbs *harken*, *wieden* en *spitten*). In addition, the verbs were matched for length ($N_{\text{letters}} = 8.4$, 8.5, and 8.4 for heterophones, homophones and homographs respectively) and for log frequency ($\ln(\text{freq}) = 5.4$, 5.5, and 5.3 for the different types; lemma frequencies based on the 42,380,000 tokens from the Celex data base; Baayen, Piepenbrock, & van Rijn, 1993). Because the present and past tense of heterophonic and homophonic verbs were obtained by adding respectively *-en* and *-d/ten* to the root, there was a difference of maximally one letter between both tenses for these verbs.

Procedure. The test sentences were distributed over participants according to a latin-square design, so that each participant saw only one sentence of a sextet. The test sentences were embedded in 174 filler sentences that were either first sentences of Dutch novels and detective stories ($N = 48$) or sentences that addressed a number of divergent psycholinguistic issues ($N = 126$). Twenty-five of the filler items were immediately followed by a yes/no question related to the content of the sentence. The purpose of the questions was to ensure that participants read the sentences in order to understand them.

Participants were seated in front of a 14 in. VDU connected to a microcomputer. Stimuli were presented on line 10 of the 80×25 character space of MS-DOS default text mode, and on line 12 if the sentence consisted of two lines of text. The experiment was divided in three blocks: one practice block of 15 sentences and two test blocks of 96 sentences. A trial started with one or two lines of dots indicating the structure of the sentence. The dot patterns were obtained by converting each letter of the sentence into a dot. Participants had to press the space bar of the computer keyboard to change the dots to the desired text fragment. Participants paced through the sentences in a series of phrases. These were obtained by displaying the content words together with their possible articles and prepositions. Thus, sentence (1a) would be segmented as follows (each slash indicates a new segment): *Terwijl/de moeders/harken/in de tuin/zitten/de vaders/in hun luie stoel.* Presentation was noncumulative. That is, each display was removed from the screen and replaced by dots as the next display went up. Reading times for the segments were measured to the nearest millisecond using procedures developed by Bovens and Brysbaert (1990) and Brysbaert (1990).

Participants were asked to read the sentences in order to understand the content. They were told not to memorize the sentences, just to read them. The order of sentences was different for each participant and obtained with the permutation algorithm outlined in Brysbaert (1991). If a sentence was encountered that had a question following it, upon the participant's keypress indicating the end of the sentence, the sentence disappeared and the question was presented on the 16th text line. The reader had to indicate his/her answer by pressing a button with the right (yes) or the left (no) hand. Feedback was given by the presentation of a wrong! message if necessary. Participants made on the average 2.6 mistakes, which is about 10%.

3. Results

Reading times of the segments were grouped into five regions: (i) the phrases in front of the first verb (which always included the conjunction and the subject of the subordinate clause, and sometimes the object), (ii) the verb of the subordinate clause, (iii) the prepositional phrase between the first and the second verb, (iv) the verb of the main clause, and (v) the phrases behind the second verb. Regions 2 and 4 are the critical regions because they contain the verbs. Table 1 gives the reading times of the five regions as a function of verb type.

Grand ANOVAs with three repeated measures Verb Type (three levels: heterophonic, homophonic, and homographic), Verb Tense (two levels: present and past), and Region (five levels) yielded but one significant effect both across subjects and across materials. It was, quite unsurprisingly, the main effect of Region ($F1(4,164) = 399.4$, $\mathrm{MSE} = 225832$, $P < 0.01$; $F2(4,68) = 47.8$, $\mathrm{MSE} = 808548$, $P < 0.01$). No other effect approached significance (all $F1$s and $F2$s < 1). Simple main effects for the different regions (with Verb Type and Verb Tense as repeated measures), however, indicated that the grand ANOVAs failed to detect one consistent difference, namely the main effect of Verb Type in region 4 (i.e., the verb of the main clause; see Table 1 for the details of the analyses). Post hoc comparisons (Newman–Keuls) revealed that the difference was situated between the homographs and the heterophones ($P1 < 0.05$, $P2 < 0.05$) as well as between the homographs and the homophones ($P1 < 0.05$, $P2 < 0.06$). No difference was present between the heterophones and the homophones; nor did the tense of the verb interact with any of the above findings.

3.1. Discussion

As indicated in Section 1, there were three possible patterns of results for the materials presented in Experiment 1. First, if non-phonological information is easily overlooked, as suggested by phrase evaluation and proofreading studies, then one

Table 1
Region reading times of Experiment 1 as a function of verb type, together with the F-values for the simple main effect of verb type within each region

	Region reading time (ms)				
	1	2	3	4	5
	Terwijl/de moeders	harken	in de tuin	zitten	de vaders/in hun luie stoel
Heterophonic	1836	741	939	583	1837
Homophonic	1832	719	939	579	1857
Homographic	1812	735	968	642	1799
$F1(2,82)$	0.09	0.25	0.18	4.59*	0.52
$F2(2,34)$	0.19	0.20	0.39	3.60*	0.47

* $P < 0.05$.

would expect the readings times of the disambiguating verb in the main clause (Region 4) to show the order heterophonic < homophonic ⩽ homographic. Second, if information revealed by homophones is more difficult to extract, then one expects longer reading times for the verbs of the subordinate clause, and the reading times of Region 2 should show the order heterophonic = homographic < homophonic. Finally, if information is extracted with the same ease from homophones as from heterophones, one would predict reading difficulties in Region 4 for homographic sentences only (i.e., heterophonic = homophonic < homographic) and no differences in Region 2. The last pattern is exactly the pattern we obtained.

A criticism one may have against Experiment 1, however, is that participants were highly motivated to disambiguate the tense of the sentence as soon as possible to reduce the processing load. So, it was strategically interesting for them to pay attention to orthographic cues. Indeed, several researchers (e.g., Rayner et al., 1998; Van Orden et al., 1999) have shown that phonological effects in visual word recognition are particularly strong when the context is highly constraining to one or the other interpretation of the homophonic pair. When the context is less constraining, readers seem to take the orthography more into account. Van Orden et al. (1999) even claimed that the interaction between contextual constraints (as implemented by the task) and reliance on orthographic/phonological information should be the cornerstone of psycholinguistic research on word processing. Or as they wrote (p. 71): "To understand the role of phonology in reading, we propose that context-induced phonology effects and their occasional context-induced absence imply a context-sensitive interactive system ... What swimming says about reading is this: It makes as little sense to speak of word identities and phonology outside of a context of discourse as to speak of swimming outside of a context of water or gravity."

We used van Heuven's (1978) design, because we wanted to see how readers deal with pure orthographic information in a normal reading situation. However, as we have seen, such a situation is not neutral with respect to the degree of reliance on phonological vs. orthographic information. Also, it may be questioned to what extent the situation is ecologically valid, as in normal reading the tense of a verb is often heavily constrained by the preceding discourse. Therefore, we decided to replicate Experiment 1 with context sentences that heavily biased the participants.

4. Experiment 2

In Experiment 2, we replicated Experiment 1, but this time the critical sentence was preceded by another sentence that heavily induced a present tense expectation. For instance, sentences (1–3) were preceded by the sentence *Ziehier een idyllisch lentetafereeltje.* [Look what an idyllic spring scene we have here.] This leading sentence was followed by one of the six versions of the different sentences. In order not to make the participants suspicious about the tense to be expected, the critical sentences were immersed in a large number of other sentences that addressed various other types of garden-path structures (e.g., the sentences used by Brysbaert & Mitchell, 1994, 1996). In addition, because we were interested in differences between the two tenses, we doubled the number of test sentences in order to keep the power of the design.

4.1. Method

Participants. Sixty first-year students from Ghent University participated for course credits. They were all native Dutch speakers, and they were not informed about the research hypothesis.

Stimulus materials. In addition to the 18 sextets of sentences from Experiment 1, 18 new sextets were constructed along the same lines (see Appendix B). Mean ln(freq) of the verbs of the subclauses was 4.1, 4.0, and 4.0 for heterophonic, homophonic, and homographic verbs respectively. The lengths were 9.8, 10.1, and 9.8 letters. The stimuli were preceded by an introduction sentence that strongly induced the expectation of the present tense (see Appendices).

Procedure. The test sentences were presented together with 279 filler trials, 25 of which were followed by a yes/no question. About half of the filler trials consisted of two sentences, so that the materials used for the present experiment did not stand out due to this feature. The experiment consisted of four parts: First 15 practice trials were presented, followed by three blocks of 105 trials. For the rest, stimulus presentation and instructions were exactly the same as in Experiment 1.

4.2. Results and discussion

Reading times of the segments were grouped into one context region and five sentence regions. The context region included all the segments of the introduction sentence. The sentence regions were the same as in Experiment 1, that is: (i) the phrases in front of the first verb (which always included the conjunction and the subject of the subordinate clause, and sometimes the object), (ii) the verb of the subordinate clause, (iii) the prepositional phrase between the first and the second verb, (iv) the verb of the main clause, and (v) the phrases behind the second verb. Table 2 gives the reading times of the six regions as a function of verb type. Sentence Regions 2 and 4 are the critical regions.

Grand ANOVAs with three repeated measures Verb Type (three levels: heterophonic, homophonic, homographic), Verb Tense (two levels: present and past), and region (five levels) yielded but two significant effects both across subjects and across materials. These were the effects of tense ($F1(1,59) = 4.68$, MSE = 72435, $P < 0.05$; $F2(1,30) = 4.63$, MSE = 43959, $P < 0.05$; [2]) and region ($F1(5,295) = 714.48$, MSE = 31991, $P < 0.01$; $F2(5,150) = 114.97$, MSE = 1161744, $P < 0.01$). Separate analyses for the different regions indicated a significant effect of verb tense in

[2] Because there were large individual differences in reading speed, which were not completely averaged out by the grouping of 10 participants per latin-square group, the latin-square group had to be included in the $F2$ design as a between-materials variable. Otherwise, there was too much spurious error variance due to reading differences of the groups.

Table 2
Region reading times of Experiment 2 as a function of verb type and verb tense, together with the F-values within each region

	Region reading time (ms)					
	Context Ziehier een idyllisch lentetafereeltje	1 terwijl/de moeders	2 harken	3 in de tuin	4 zitten	5 de vaders/ in hun luie stoel
Heterphonic						
Present	2487	1864	659	785	578	1690
Past	2515	1847	690	801	556	1743
Homophonic						
Present	2505	1882	654	815	569	1671
Past	2535	1863	707	816	584	1737
Homographic						
Present	2486	1800	633	770	555	1641
Past	2512	1866	659	786	590	1696
$F1$ ($df = 1$ or 2, 59 or 118)						
Verb type	<1	<1	1.79	1.04	<1	<1
Verb tense	<1	<1	8.46*	<1	<1	7.69*
Interaction	<1	<1	<1	<1	3.48*	<1
$F2$ ($df = 1$ or 2, 30 or 60)						
Verb type	<1	<1	2.27	1.72	<1	1.58
Verb tense	<1	<1	7.15*	<1	<1	6.64*
Interaction	<1	1.03	<1	3.48*	3.01**	<1

* $P < 0.05$.
** $P < 0.10$.

Region 2 (the verb of the subclause) and Region 5 (the end of the sentence), and an interaction between verb tense and verb type in Region 4 (the disambiguating verb of the main clause; see Table 2 for details of the analysis).

The effect of verb tense in Region 2 was expected for the heterophonic verbs, possibly for the homophonic verbs, but not for the homographic verbs, because for the last verb type the verb forms are the same in the present and the past. However, a closer look revealed: (i) that the difference for the homographic verb tenses was due to slightly faster reading times in the present conditions (relative to the other present conditions) and not to slower reading times in the past conditions, and (ii) in no analysis did the difference reach significance ($F1(1,59) = 1.20$; $F2(1,30) = 1.73$). In contrast, the difference was significant for the homophonic verbs ($F1(1,59) = 4.98$, $P < 0.05$; $F2(1,30) = 3.02$, $P < 0.10$), but again not quite so for the heterophonic verbs ($F1(1,59) = 3.12$, $P < 0.10$; $F2(1,30) = 1.15$, n.s.).

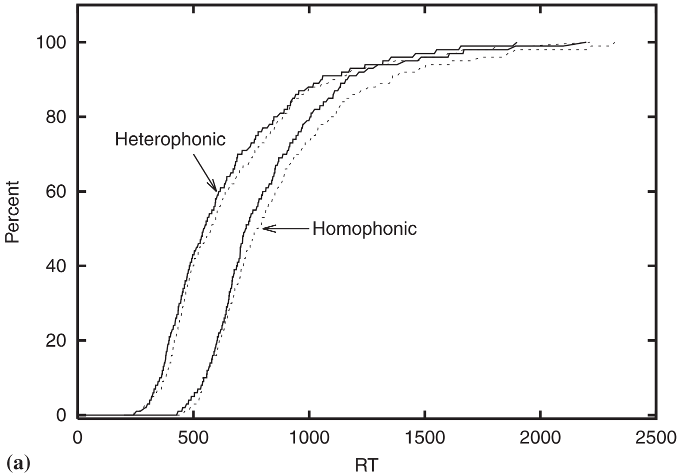
The interaction between verb type and verb tense in Region 4 (verb of the main clause) was, as expected, mostly due to the difference between present and past for the homographic verbs ($F1(1,59) = 2.88$, $P < 0.10$; $F2(1,30) = 4.92$, $P < 0.05$). The other differences did not approach significance (heterophonic: $F1(1,59) = 1.57$; $F2(1,30) = 2.00$; homophonic: $F1(1,59) = 1.10$; $F2(1,30) < 1$), although it may be noted that the difference between present and past verb forms was not exactly the same for heterophonic verbs (past faster than present) and homophonic (past slower than present). The power of the design does not allow us to draw firm conclusions about this finding (also not because in Region 3, there was a difference in the opposite direction), but it may suggest that there are some small processing costs associated with homophonic verbs, maybe because pure orthographic information is harder to retain in the addressed phonology needed for text comprehension (see Section 1).

Another reason for the small time differences in Region 4 between homophonic sentences and heterophonic sentences, may be that we used an inappropriate test to look for processing differences in Region 2. It may be argued that an ANOVA is not a good test to look for differences between heterophonic and homophonic verbs, because a pattern of results that would fit well with the strong phonological models of visual word recognition is that homophonic errors are missed on a significant percentage of cases, but lead to extra processing problems in the other cases. The net result may very well be a null difference between the average reading times. To examine this possibility, we looked at the cumulative distributions of reading times in the different conditions. If the information disclosed by the homophonic verbs is missed in a significant number of cases, then the lower part of the distribution for the past tense should be the same as the lower part for the present tense (because the processing problem is not noted). Only in the upper part should there be a divergence. In addition, if the past tense of the homophonic verbs is processed differently than the past tense of the heterophonic verbs, there should be a notable difference between the cumulative functions of these two conditions. Fig. 1 tests these predictions: Panel (a) compares the present and past tenses for the heterophonic and the homophonic verbs; panel (b) compares the heterophonic and the homophonic verbs for the present tense and the past tense. As can be seen, none of the predictions came out. The distributions of the present and the past tense diverge from the smallest values on, both for homophonic verbs and heterophonic verbs; and the distributions of the past tense of the heterophonic and the homophonic verbs completely overlap. The obvious conclusion, therefore, is that both types of verbs were treated in the same way.

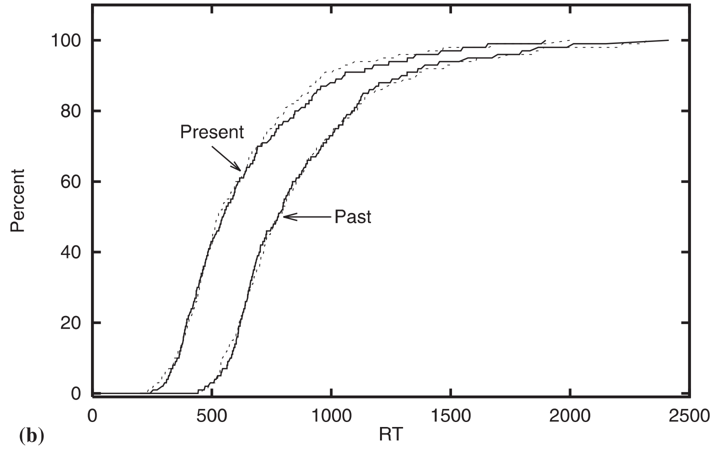
Finally, at the end of the sentence (Region 5), there was a 60 ms extra time needed for sentences written in the past than for sentences written in the present. An extra wrap-up at the end of the sentence has been seen for other materials with processing difficulties as well (Brysbaert & Mitchell, 1996; Mitchell et al., in press), and confirms that our leading sentences indeed biased the participants towards a present interpretation. The effect of the past tense on the final region does not differ for the different types of verbs.

5. General discussion

In this article, we started from the observation that phonologically dominated models of visual word recognition account best for a wide range of recently



(a)



(b)

Fig. 1. (a) Cumulative distributions of the reading times of Region 2 (Experiment 2), as a function of verb type (heterophonic vs. homophonic) and verb tense (full line = present; dashed line = past). For presentation purposes, the distributions of the homophonic verbs have been shifted 200 ms to the right. (b) Cumulative distributions of the reading times of Region 2 (Experiment 2), as a function of verb tense (present vs. past) and verb type (full line = heterophonic; dashed line = homophonic). For presentation purposes, the distributions of the past tense have been shifted 200 ms to the right.

discovered phonological effects in visual word processing. Although many authors still believe the phonologically mediated pathway is accompanied by a direct route from orthography to meaning (e.g., Grainger & Ferrand, 1996; Plaut et al., 1996; Xu et al., 1999), the case has been made that the evidence for such a direct connection is very scarce and has been diminishing in recent years (Frost, 1998; Lukatela & Turvey, 1994; Van Orden et al., 1990). Thus, it was of interest to examine what happens when a written language reveals important morphological information that is not retained in the phonology. As indicated in the introduction, the question had a theoretical as well as a practical motivation.

From a theoretical point of view, the simplest finding probably would have been a time cost for the homophonic verbs, comparable to the time cost of the homographic verbs, and significantly larger than the time cost of the heterophonic verbs. This would have been consistent with many recent findings and would have formed yet another indication that phonology plays a crucial role in visual word recognition. However, this is not quite the pattern we obtained. In two experiments, we found that homophonic verbs were processed very much like heterophonic verbs, even when the context heavily constrained the reader to one interpretation of the homophonic verb forms. The finding is not a null-effect, as the reading pattern of homophonic verbs differed significantly from that of homographic verbs.

The most straightforward interpretation of our finding is that in visual word recognition there is a distinct connection between orthography and meaning, that helps to resolve any ambiguity raised by the phonology. Unlike the claims made by different authors, these ambiguities are not rare, as several languages include morphological cues in their written form that are not present in the spoken form. So, there may be reasons why a structural change in the brain emerges during reading acquisition and why direct access from orthography to meaning is helpful. As such, we may have discovered another paradigm that yields positive evidence for the existence of an independent orthographic route.

On the other hand, the literature of pure orthographic effects (see the introduction) warns us not to overstate the theoretical importance of our finding. In addition, some recent work by Kempen, Kooij, & van Leeuwen (1997) suggests that the attention paid to non-phonological, orthographic information may not be the default value of the reading system but may have been induced by the specific homophonic verb forms we used. Kempen et al. (1997) started from another phonological ambiguity in Dutch verb forms: that between the present third person singular, and the past participle. Just like in van Heuven's structure, some of these verb forms are heterophonic (e.g. *verliest* [loses] vs. *verloren* [lost]), others are homophonic (e.g., *verspeelt* [gambles away] vs. *verspeeld* [gambled away]), and still others are homographic (e.g., *verkwist* [wastes] vs. *verkwist* [wasted]). Kempen et al. presented these verb forms in a structure that is likely to elicit a garden-path effect (i.e., a syntactic misinterpretation), as is shown in the following examples:

(7) Die baron die vorig jaar nog een vermogen had verliest nu zijn laatste centen.
[That baron who last year still a fortune had loses now his last pennies.]

(8) Die baron die vorig jaar nog een vermogen had verspeelt nu zijn laatste centen.
[That baron who last year still a fortune had gambles away now his last pennies.]

(9) Die baron die vorig jaar nog een vermogen had verkwist nu zijn laatste centen.
[That baron who last year still a fortune had wastes now his last pennies.]

This structure is likely to elicit a misinterpretation in (9) due to the ambiguity introduced by the sequence *had verkwist* [had wastes/wasted]. The verb *had* is categorically ambiguous between a main verb and an auxiliary, the verb form *verkwist* is inflectionally ambiguous between past participle and finite verb. Most readers prefer to take *had* as auxiliary and *verkwist* as past participle, because *had* is much more frequent as an auxiliary, and because readers usually prefer to incorporate new incoming information within the syntactic node currently being processed (i.e., the late closure principle; Frazier, 1978). Therefore, readers prefer much more a sentence like (10):

(10) Die baron die vorig jaar nog een vermogen had verkwist spendeert nu zijn laatste centen.

[That baron who last year a fortune had wasted spends now his last pennies.]

Question now is how sentences (7) and (8) will be processed in comparison with sentence (9). Sentence (9) is fully ambiguous (i.e., homographic), sentence (8) adds an orthographic cue to the right interpretation (homophonic), and sentence (7) adds both an orthographic and a phonological cue (heterophonic). Data from several studies run by Kempen and colleagues show that the garden path effect was equally large for the homophonic and the homographic verbs, and considerably larger than the effect for the heterophonic verbs, as predicted by the strong phonological models of reading and against our current findings. However, when Kempen et al. added a fourth type of verbs to their design, the reading data came closer to our results. This type of verbs consisted of homophonic verb forms with a strong orthographic cue, as shown in (11):

(11) Die baron die vorig jaar nog een vermogen had verwedt nu zijn laatste centen.

[That baron who last year still a fortune had stakes now his last pennies.]

The difference between sentences (8) and (11) is that, although both verbs are homophonic verb forms, the end letters -*dt* of *verwedt* in sentence (11) are only possible as an inflection of Dutch verbs, whereas the end letters -*lt* of *verspeelt* occur in many other words (e.g., *eelt* [hard skin] and *milt* [spleen]). Similarly, the spelling patterns -iedd-and -stt-we used in our homophonic sentences only occur in polymorphic words, such as verb inflections (e.g. sentence 2b) or compositions (e.g., *handdruk* [handshake], *feesttent* [party tent]). According to Kempen et al. (1997) such spelling patterns may trigger specialised orthographic morpho-syntactic analysers. Hence, the immediate use of the orthographic cues in sentence (11) and in our sentences.

On the other hand, it should be noted that there is evidence that the syntactic parser not always takes into account all lexical information when it decides which interpretation to follow (e.g., Brysbaert & Mitchell, in press; Mitchell, Cuetos, Corley, & Brysbaert, 1995). For instance, in Brysbaert & Mitchell (in press) we presented sentence (12) in a questionnaire to 100 students and asked who or what called up emotions of endearment:

(12) De oude vrouw keek naar de teddybeer van het kindje dat gevoelens van vertedering opriep.

[The old lady looked at the teddy beer of the child that emotions of endearment called up.]

Of the students, 42% thought it was the teddy beer that called up the emotions of endearment, despite the fact that the relative pronoun *dat* unambiguously pointed to the child [which is the only noun with a neuter gender, asking for the relative pronoun *dat*, instead of *die*]. Note that the misanalysis occurred despite the fact that the relative pronoun *dat* differs substantially from the relative pronoun *die* both in orthographic and phonological features. In this respect, it is not without importance that in the Kempen et al. studies, the sentences with heterophonic verb forms (i.e., sentence 7) induced a garden-path effect as well, even though it was smaller than the one induced by sentences (8) and (9). So, the sentences of Kempen et al. may say more about the power of phonological and orthographic cues to prevent the syntactic parser from following its preferred interpretation than about the use of visual and auditory information in word recognition.

Anyway, the findings of Kempen et al. (1997) suggest that we should be careful about the interpretation of our findings. Our data indicate that the reading system is sensitive to orthographic information that is not represented on the phonological level, but they do not allow us (yet) to conclude whether this is the normal way of text reading, or whether it is elicited by specific morpho-syntactic cues. As such, the theoretical implications of our findings may be limited to showing that the reading system is tuned to processing difficulties it is likely to encounter on the basis of phonological coding, and that this kind of morpho-syntactic sensitivity should be incorporated in any strong phonological model of visual word recognition.

From a practical point of view, however, it does not matter whether the sensitivity to homophonic verb forms is the result of a direct route from orthography to meaning or whether it is due to special back-up strategies. The bottom line here is that orthographic information which does not have a phonological counterpart is used to make out the right interpretation of the text. For many Dutch readers, this will be a relief: The verb forms that are so tricky to write correctly, have a function in reading. Hence, not all efforts to master them, are in vein (sic).

Appendix A

Stimuli used in Experiments 1 and 2 (literal translation; for reasons of space economy, only the present tenses are given; the sequence of verbs always is heterophonic, homophonic, and homographic; the introduction sentences were not used in Experiment 1).

1. Ziehier een idyllisch lentetafereeltje. Terwijl de moeders harken (wieden, spitten) in de tuin zitten de vaders op hun luie stoel.
   [Look what an idyllic spring scene we have here. While the mothers are raking (weeding, digging) in the garden the fathers are sitting in their armchair.]
2. Daaraan herken je een echte autofanaat. Zolang de auto's niet aftakelen (roesten, verrotten) in de garages vinden wij ze mooi.
   [This is how you recognise a real car fanatic. As long as the cars don't creak (rust, rot) in the garages we like them.]
3. Zo ziet een typisch Vlaamse vakantie eruit. Terwijl de ouders fuiven (feesten, dutten) aan de zee lezen de kinderen een boek.
   [This is what typical Flemish holidays look like. While the parents have a party (have a party, are sleeping) at the sea the children are reading a book.]
4. Een rangeerterrein bij nacht biedt een boeiend schouwspel. Terwijl de lampen zwaaien (branden, schudden) aan de kabels trekken de treinen op.

[A shunting-yard at night is a fascinating spectacle. While the lamps are swinging (burning, swinging) at the cables the trains are accelerating.]

5. Vandaag is het Waregem Koerse. Terwijl de mannen geld verspillen (verkwisten, verwedden) op de tribunes beginnen de races.

   [Today it's Waregem's steeplechase. While the men are wasting (wasting, staking) money on the stands the races begin.]

6. Het is momenteel zo'n 30 graden in de schaduw. Terwijl de kinderen joelen (wroeten, ravotten) in de zandbak blijven de ouders binnen.

   [It is 30° in the shadow now. While the children are whooping (rooting, romping) in the sandbox the parents stay inside.]

7. De elite-eenheid staat klaar. Zodra de terroristen de politie ontstemmen (misleiden, bedotten) met allerlei dreigementen kruipen sluipschutters naar het gebouw.

   [The elite troops are ready. As soon as the terrorists dismay (rag, fool) the police with all sorts of threats snipers steal into the building.]

8. Ook dit is Kerstmis. Terwijl de vrouwen zich schminken (aankleden, optutten) voor het feest, rijden de mannen de auto voor.

   [This is Christmas too. While the wives are making up themselves (getting dressed, tarting up themselves) the men drive up the car.]

9. In de bloemensector heeft men geen last van de crisis. Zolang de bloemisten mooie bloemen kweken (planten, zetten) in hun serres krijgen ze veel klanten over de vloer.

   [In the flower sector they don't feel the crisis. As long as florists cultivate (plant, place) beautiful flowers in their conservatories they have many customers.]

10. Hier is duidelijk een tuchtprobleem. Niettegenstaande de jongens de meisjes uitlachen (pesten, bespotten) op de speelplaats blijven de leraars binnen.

    [Here we clearly have a problem of discipline. Although the boys laugh at (pester, ridicule) the girls in the playground the teachers stay inside.]

11. Zo erg is een televisiekwis. Terwijl de deelnemers het aantal knikkers gissen (raden, schatten) in de bokaal zoeken de organisatoren de prijzen bijeen.

    [So bad is a television quiz. While the participants guess (guess, estimate) the number of marbles in the beaker the organisers search for prices.]

12. Deze nachtmerrie is weldra voorbij. Zodra de gidsen de verdwaalde toeristen weghalen (bevrijden, ontzetten) uit het oerwoud kunnen de familieleden tevreden naar huis terugkeren.

    [This nightmare will soon be over. As soon as the guides remove (free, rescue) the tourists out of the forest the family members can return happily home.]

13. Daar hoef je je geen zorgen over te maken. Zolang wij de bloemen jaarlijks verhuizen (verplanten, verpotten) in verse grond blijven ze doorgroeien.

    [You do not have to worry about that. As long as we remove (transplant, repot) the flowers in fresh sand once a year they keep on growing.]

14. Het heeft geen zin om nu nog op jacht te gaan in de velden. Zodra de boeren hun land ploegen (bemesten, ontsmetten) in het voorjaar wijken de patrijzen uit naar het bos.

[There is no point now going chasing in the open country. As soon as the farmers plough (manure, disinfect) their grounds in springtime the partridges flee to the woods.]

15. Iedere minuut telt nu. Terwijl bacteriën het lichaam steeds verder verzwakken (aantasten, besmetten) bij de patiënt proberen de dokters tevergeefs verschillende soorten antibiotica uit.
    [Each minute counts now. While bacteria enfeeble (affect, infect) the body of the patient more and more the doctors in vain try out several kinds of antibiotics.]
16. Deze kritiek is onterecht.Niettegenstaande de leraars de vrijheid van de leerlingen afremmen (betwisten, beknotten) in de klas wordt de creativiteit toch niet helemaal onderdrukt.
    [This criticism is without cause. Although the teachers curb (contest, restrict) the freedom of the pupils in the classroom the creativity is never completely suppressed.]
17. We verwachten een acute crisissituatie. Zodra de Verenigde Naties hun noodhulp beëindigen (opschorten, stopzetten) in het vluchtelingenkamp breekt er paniek uit.
    [We expect an acute crisis situation. As soon as the United Nations terminate (suspend, stop) the emergency aid in the refugee camp panic breaks out.]
18. Dat is hun eigen schuld. Ofschoon verkeersborden aansporen (aanraden, aanzetten) het bosdreefje niet te gebruiken zijn er toch veel automobilisten die de aanbeveling negeren.
    [It's their own mistake. Although road signs urge (advise, spur on) not to use the wood-path a lot of drivers ignore the recommendation.]

Appendix B

Additional sentences of Experiment 2.

1. Het is weer druk in de keuken vandaag. Terwijl de keukenhulpjes de appelen schillen (bereiden, wegzetten) in een kom kloppen de koks het deeg op.
2. Ouderliefde gaat heel ver. Niettegenstaande de kinderen geregeld het behang bemorsen (verwoesten, bekladden) met verf blijven hun ouders van hen houden.
3. Goede wil volstaat niet. Hoewel de sociale wetten de kansarmen beveiligen (behoeden, beschutten) tegen de grootste tegenslagen zijn er toch veel die armoede lijden.
4. Sociale onrust is hier nooit ver weg. Zodra de vakbondsmilitanten de arbeiders opstoken (ompraten, opjutten) tegen de bazen valt aan een staking niet meer te ontkomen.
5. Een ochtend in de fabriek verloopt als volgt. Terwijl de werklieden de stukken aaneenvoegen (aaneenhechten, aaneenzetten) in het atelier rijden verkopers rond om die te verkopen.
6. De sociale onrust breidt uit. Terwijl de onderhandelaars hun besprekingen voltooien (afronden, hervatten) in het regeringsgebouw scanderen betogers op straat.

7. In de kinderkribbe heerst weer eens chaos. Terwijl de peuters de speelgoedzak leeggooien (leegstorten, leegschudden) op de grond probeert de kinderoppas de radio te herstellen.
8. Mijn kinderen zijn dol op het circus. Terwijl de clowns de olifanten afbeulen (africhten, afmatten) op de piste komen hulpjes rond met zakken confetti.
9. Het bedrijf is optimistisch. Hoewel meerdere prototypes uiteenklappen (uiteenbarsten, uiteenspatten) tijdens de testfase blijven de ingenieurs geloven in het concept.
10. Maakt u zich geen zorgen. Zodra de meubelen verkolen (opbranden, vlamvatten) in het bejaardentehuis aarzelen de brandweerlui niet om de hele zaak onder water te spuiten.
11. Hoe kan je nu vooruitgang boeken? Zolang de bemiddelaars de grote lijnen niet afbakenen (aankaarten, samenvatten) tijdens hun gesprekken wordt er veel in het ijle gebabbeld.
12. Het grootste werk is achter de rug. Terwijl de schilders de potten verf bijeenplaatsen (bijeenladen, bijeenzetten) in hun bestelwagen rekent de ploegbaas af.
13. Het conflict blijft voortduren. Terwijl de studenten hun acties verlengen (inkorten, voortzetten) in de grote steden zoeken de ministers naar een oplossing voor het probleem.
14. We zullen het moeten aanvaarden. Zolang wij de juiste strategie niet toepassen (aanwenden, benutten) voor onze moeilijkheid blijft de kwestie onopgelost.
15. In deze klas worden de verantwoordelijkheden gedeeld. Terwijl de leerlingen het vraagstuk aanpakken (ontleden, aanvatten) in kleine groepjes verbetert de leraar hun huiswerk.
16. Zo zie ik het niet. Hoewel de plattelandsbewoners hun lakens wekelijks uitkloppen (uitspreiden, uitschudden) in de zon zijn ze niet hygiënischer dan stedelingen.
17. In het Witte Huis hangt een huiselijke sfeer. Hoewel de presidentsvrouwen af en toe kijven (kiften, vitten) op hun man zijn ze toch trots op wat die bereikt heeft.
18. De sociale onrust gaat zijn zesde week in. Terwijl de stakingspiketten het verkeer versperren (ontwrichten, boycotten) op het terrein dreigen de bazen met ontslagen.

References

Baayen, R. H., Piepenbrock, R., & van Rijn, H. (1993). *The CELEX lexical database* (*CD-ROM*). Linguistic Data Consortium, University of Pennsylvania, Philadelphia.

Baddeley, A. (1986). *Working memory*. Oxford: Clarendon Press.

Baddeley, A., Vallar, G., & Wilson, B. (1987). Sentence comprehension and phonological memory: some neuropsychological evidence. In M. Coltheart, *Attention and performance XII: the psychology of reading* (pp. 509–530). Hove: Erlbaum.

Baron, J. (1973). Phonemic stage not necessary for reading. *Quarterly Journal of Experimental Psychology*, *25*, 241–246.

Besner, D., & McCann, R.S. (1987). Word frequency and pattern distortion in visual word identification and production: An examination of four classes of models. In M. Coltheart, *Attention and performance XII: the psychology of reading* (pp. 201–219). Hove: Erlbaum.

Bosman, A. M. T., & de-Groot, A. M. B. (1996). Phonologic mediation is fundamental to reading: evidence from beginning readers. *Quarterly Journal of Experimental Psychology*, *49A*, 715–744.

Bovens, N., & Brysbaert, M. (1990). IBM PC/XT/AT and PS/2 Turbo Pascal timing with extended resolution. *Behavior Research Methods, Instruments, and Computers*, *22*, 332–334.

Brysbaert, M. (1990). A warning about millisecond timing in Turbo Pascal. *Behavior Research Methods, Instruments, and Computers*, *22*, 344–345.

Brysbaert, M. (1991). Algorithms for randomness in the behavioral sciences: a tutorial. *Behavior Research Methods, Instruments, and Computers*, *23*, 45–60.

Brysbaert, M., & Mitchell, D. C. (1994). Sentence parsing in Dutch: the importance of lexical influences. *Psychologica Belgica*, *34*, 99–114.

Brysbaert, M., & Mitchell, D. C. (1996). Modifier attachment in sentence parsing: evidence from Dutch. *Quarterly Journal of Experimental Psychology*, *49A*, 664–695.

Brysbaert, M., & Mitchell, D. C. (in press). The failure to use gender information in parsing: a comment on van Berkum, Brown, and Hagoort (1999). *Journal of Psycholinguistic Research*.

Brysbaert, M., & Praet, C. (1992). Reading isolated words: no evidence for automatic incorporation of the phonetic code. *Psychological Research*, *54*, 91–102.

Brysbaert, M., Van Dyck, G., & Van de Poel, M. (1999). Visual word recognition in bilinguals: evidence from masked phonological priming. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 137–148.

Buchanan, L., Hildebrandt, N., & MacKinnon, G. E. (1996). Phonological processing of nonwords in deep dyslexia: typical and independent?. *Journal of Neurolinguistics*, *9*, 113–133.

Caspari, I., Parkinson, S. R., LaPointe, L. L., & Katz, R. C. (1998). Working memory and aphasia. *Brain and Cognition*, *37*, 205–223.

Chen, H. C., d'Arcais, G. B. F., & Cheung, S. L. (1995). Orthographic and phonological activation in recognizing Chinese characters. *Psychological Research*, *58*, 144–153.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood, *Strategies of information processing.* London: Academic Press.

Daneman, M., & Stainton, M. (1991). Phonological recoding in silent reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 618–632.

Davis, C., Castles, A., & Iakovidis, E. (1998). Masked homophone and pseudohomophone priming in children and adults. *Language and Cognitive Processes*, *13*, 625–651.

Evett, L. J., & Humphreys, G. W. (1981). The use of abstract graphemic information in lexical access. *Quarterly Journal of Experimental Psychology*, *33A*, 325–350.

Ferrand, L., & Grainger, J. (1993). The time course of orthographic and phonological code activation in the early phases of visual word recognition. *Bulletin of the Psychonomic Society*, *31*, 119–122.

Ferrand, L., & Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming. *Quarterly Journal of Experimental Psychology*, *47A*, 365–382.

Fleming, K. (1993). Phonologically mediated priming in spoken and printed recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 272–284.

Forster, K. I. (1990). Lexical processing. In D. N. Osherson, & H. Lasnik, *Language: an invitation to cognitive science* (Vol. 1, pp. 95–131). Cambridge, MA: MIT Press.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: true issues and false trails. *Psychological Bulletin*, *123*, 71–99.

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: cross-task comparisons. *Journal of Memory and Language*, *35*, 623–647.

Gronau, N., & Frost, R. (1997). Prelexical phonologic computation in a deep orthography: evidence from backward masking in Hebrew. *Psychonomic Bulletin and Review*, *4*, 107–112.

Humphreys, G. W., & Evett, L. J. (1985). Are there independent lexical and nonlexical routes in word processing? An evaluation of the dual-route theory of reading. *Behavioral and Brain Sciences*, *8*, 689–740.

Humphreys, G. W., Evett, L. J., & Taylor, D. E. (1982). Automatic phonological priming in visual word recognition. *Memory and Cognition*, *10*, 576–590.

Katz, R. B., & Lanzoni, S. M. (1992). Automatic activation of word phonology from print in deep dyslexia. *Quarterly Journal of Experimental Psychology*, *45A*, 575–608.

Kempen, G., Kooij, A., & van Leeuwen, (1997). Do skilled readers exploit inflectional spelling cues that do not mirror pronunciation? An eye movement study of morpho-syntactic parsing in Dutch. In *Abstracts of the orthography work-shop "What spelling changes"*. Nijmegen: Max Planck Institute for Psycholinguistics.

Lee, H. W., Rayner, K., & Pollatsek, A. (1999). The time course of phonological, semantic, and orthographic coding in reading: evidence from the fast-priming technique. *Psychonomic Bulletin and Review*, *6*, 624–634.

Lesch, M., & Pollatsek, A. (1993). Automatic access of semantic information by phonological codes in visual word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 285–294.

Levy, B. A. (1977). Reading: speech and meaning processes. *Journal of Verbal Learning and Verbal Behavior*, *16*, 623–638.

Lukatela, G., & Turvey, M. T. (1994). Visual lexical access is initially phonological: I. Evidence from associative priming by words, homophones, and pseudohomophones. *Journal of Experimental Psychology: General*, *123*, 107–128.

Luo, C. R., Johnson, R. A., & Gallo, D. A. (1998). Automatic activation of phonological information in reading: evidence from the semantic relatedness decision task. *Memory and Cognition*, *26*, 833–843.

McCutchen, D., Dibble, E., & Blount, M. M. (1994). Phonemic effects in reading-comprehension and text memory. *Applied Cognitive Psychology*, *8*, 597–611.

McCutchen, D., & Perfetti, C. A. (1982). The visual tongue twister effect: phonological activation in silent reading. *Journal of Verbal Learning and Verbal Behavior*, *21*, 672–678.

Mitchell, D. C., Brysbaert, M., Grondelaers, S., & Swanepoel, P. (in press). Modifier attachment in Dutch: Testing aspects of Construal Theory. In A. Kennedy, R. Radach, D. Heller, & J. Pynte, *Reading as a perceptual process*. Oxford: Elsevier.

Mitchell, D. C., Cuetos, F., Corley, M. M. B., & Brysbaert, M. (1995). Exposure-based models of human parsing: evidence for the use of coarse-grained (non-lexical) statistical records. *Journal of Psycholinguistic Research*, *24*, 469–488.

Nas, G. (1983). Visual word recognition in bilinguals: evidence for a cooperation between visual and sound based codes during access to a common lexical store. *Journal of Verbal Learning and Verbal Behavior*, *22*, 526–534.

Neisser, U. (1967). *Cognitive psychology*. New York: Appleton-Century-Crofts.

Patterson, K., & Coltheart, V. (1987). Phonological processes in reading: a tutorial review. In M. Coltheart, *Attention and performance XII: the psychology of reading* (pp. 421–447). Hove: Erlbaum.

Perfetti, C. A., & Bell, L. C. (1991). Phonemic activation during the first 40 ms of word identification: evidence from backward masking and priming. *Journal of Memory and Language*, *30*, 473–485.

Perfetti, C. A., Bell, L. C., & Delaney, S. M. (1988). Automatic (prelexical) phonetic activation in silent word reading: evidence from backward masking. *Journal of Memory and Language*, *27*, 59–70.

Perfetti, C. A., & Zhang, S. (1995). Very early phonological activation in Chinese reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 24–33.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: computational principles in quasi-regular domains. *Psychological Review*, *103*, 56–115.

Pollatsek, A., Lesch, M., Morris, R. K., & Rayner, K. (1992). Phonological codes are used in integrating information across saccades in word identification and reading. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 148–162.

Pynte, J. (1974). Readiness for pronunciation during the reading process. *Perception and Psychophysics*, *16*, 110–112.

Rayner, K., Pollatsek, A., & Binder, K. S. (1998). Phonological codes and eye movements in reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *24*, 476–497.

Rayner, K., Sereno, S. C., Lesch, M. F., & Pollatsek, A. (1995). Phonological codes are automatically activated during reading: evidence from an eye movement priming paradigm. *Psychological Science*, *6*, 26–32.

Rubenstein, H., Lewis, S. S., & Rubenstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behavior*, *10*, 645–657.

Sandra, D., Frisson, S., & Daems, F. (1999). Why simple verb forms can be so difficult to spell: the influence of homophone frequency and distance in Dutch. *Brain and Language*, *68*, 277–283.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed developmental model of word recognition and naming. *Psychological Review*, *96*, 523–568.

Slowiaczek, M. L., & Clifton, C. (1980). Subvocalization and reading for meaning. *Journal of Verbal Learning and Verbal Behavior*, *19*, 573–582.

Taft, M., & van Graan, F. (1998). Lack of phonological mediation in a semantic categorization task. *Journal of Memory and Language*, *38*, 203–224.

Van Cauteren, E. (1997). *Fonologische hercodering van visueel aangeboden woorden en de vraag naar contextafhankelijkheid in de Nederlandse taal*. Unpublished Master's thesis. University of Leuven.

van der Velde, I. (1956). *De tragedie der werkwoordsvormen, een taalhistorische en taaldidactische studie.* Groningen: Wolters.

van Heuven, V. (1978). *Spelling en lezen: Hoe tragisch zijn de werkwoordsvormen?* Assen: Van Gorcum.

Van Orden, G. C. (1987). A ROWS is a ROSE: spelling, sound and reading. *Memory and Cognition*, *15*, 181–198.

Van Orden, G. C. (1991). Phonologic mediation is fundamental to reading. In. D. Besner, & G. W. Humphreys, *Basic processes in reading*: *visual word recognition* (pp. 77–103). Hillsdale, NJ: Lawrence Erlbaum Associates.

Van Orden, G. C., & Goldinger, S. D. (1994). The interdependence of form and function in cognitive systems explains perception of printed words. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1269–1291.

Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review*, *97*, 488–522.

Van Orden, G. C., Holden, J. G., Podgornik, M. N., & Aitchison, C. S. (1999). What swimming says about reading: coordination, context, and homophone errors. *Ecological Psychology*, *11*, 45–79.

Xu, B., & Perfetti, C. A. (1999). Nonstrategic subjective threshold effects in phonemic masking. *Memory and Cognition*, *27*, 26–36.

Xu, Y. D., Pollatsek, A., & Potter, M. C. (1999). The activation of phonology during silent Chinese word reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 838–857.

Zhang, S., & Perfetti, C. A. (1993). The tongue-twister effect in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 1082–1093.