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Orthography, phonology, and semantics

Concerted action in word perception*

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A couple of decades of scientific research on printed word perception led to the emergence of a coherent picture with respect to the fundamental aspects that govern reading. Most researchers agree with the assumption that orthography (the spelling of a word), phonology (the sound of a word), and semantics (the/a meaning(s) of a word) all play a role in processing printed materials. In this paper, we focus on the concerted action of orthography, phonology, and semantics, and propose that they should be understood as emergent properties in a highly interactive, interdependent, dynamical system

We will first present a short overview of the evidence that each of these three aspects is actually contributing to the processes involved in printed word perception and then report three empirical studies. In the General Discussion, we interpret the findings in terms of the phonologic coherence model of Van Orden and his colleagues (e.g., 1990, 1994, and 1997).

Orthography

The role of orthography in reading is almost self-evident. The clearest example of how orthography exerts an essential influence on reading is the fact that experienced readers can distinguish between homophones. A homophone is a word with identical phonology to and dissimilar spelling and meaning from another word. For example, THERE and THEIR, DEAR and DEER, or WEAK and WEEK are all homophones of each other. Only orthographic information represented in these words provides unequivocal evidence of their meaning.

Another example of the role of orthography in reading is that experienced readers (Bosman, unpublished material, see Experiment 1) unlike novice readers (Bosman & de Groot, 1991; Reitsma, 1983), process words faster than pseudohomophones. A pseudohomophone is a letter string that is phonologically identical

to, but orthographically different from a word (e.g., BERD is a pseudohomophone of the word BIRD).

Coltheart and Freeman (1974) also demonstrate the role of orthography in reading. They found that words presented iN AlTeRNatIng cASe were more difficult to read than regularly written words (see also Smith, Lott, & Cronnell, 1969).

A final example of how orthography affects printed word perception is that words with many neighbours are processed more quickly and accurately than words with few neighbours (e.g., Andrews, 1989, 1992; Grainger, Spinelli, & Ferrand, 2000; Peereman & Content, 1995). Neighbourhood size is defined as the number of words that share all but one letter with the target word. For example, BARK, DARK, LARK, MARK, SARK, PERK, PORK, PACK, PARA, PARD, PARE, PARR, PART, are all neighbours of the word PARK (see for a critical remark on the partial confound between orthographic and phonographic neighbourhood, Peereman & Content, 1997).

Phonology

That phonology plays a role in (beginning) reading was never doubted, but whether and when it is an obligatory aspect of printed word perception is still a big issue among psycholinguists (see for discussions, Berent & Perfetti, 1995; Frost, 1998; Humphreys & Evett, 1985; Van Orden, Pennington, & Stone, 1990). We could fill this entire volume with empirical evidence of the role of phonology in reading, but restrict ourselves to a couple of examples.

Convincing evidence is provided in experiments in which pseudohomophone processing is compared to pseudoword processing. A pseudoword is an orthographically legal letter string with phonology dissimilar from words For example, BELF, JARL, and SKONK are English pseudowords. Naming latencies of pseudohomophones like 'BERD' are often faster than naming latencies of pseudowords like 'BELF' (e.g., Besner & Davelaar, 1983; McCann & Besner, 1987; Seidenberg, Petersen, MacDonald, & Plaut, 1996; Taft & Russell, 1992). Lexical-decision experiments show that rejection latencies of pseudohomophones are often longer and more error prone than rejection latencies of pseudowords (e.g., Bosman & de Groot, 1996; Seidenberg et al., 1996; Stone & Van Orden, 1993; Van Orden et al., 1992). It is believed that the familiar phonology of pseudohomophones interferes with its unfamiliar orthography (e.g., JALE), which in turn, causes a delay in the decision to reject the letter string. Such interference does not occur in pseudowords, because both orthography and phonology are unfamiliar (e.g., LOIP). A recent study suggests that such effects extend to second language processing (Bosman, van Hell, & Van Orden, 1998). In a proofreading task in English, in which Dutch-English bilinguals were asked to detect errors in an ongoing text, we observed that pseudohomophones were harder to detect than pseudowords.

A most elegant demonstration of the effect of phonology is a study by Stone and Van Orden (1993). They conducted experiments that involved the so-called ideal strategy manipulation, in which the same target words were embedded in a pseudohomophone context or in a pseudoword context. It appeared that correct "yes"-response latencies to words were slowed down in their lexical-decision task that included pseudohomophones as compared to one that included pseudowords. Thus, processing-time difference between these two conditions can only be attributed to the differential contexts (see also Gibbs & Van Orden, 1998; James, 1975; Vanhoy & Van Orden, 2001 and Pugh, Rexer, & Katz, 1994 for a failure to find a pseudohomophone effect).

Homophone effects are also a signature of phonology. Many readers, both beginning and experienced readers, often mistakenly judge ROWS to be a member of the category FLOWERS in lexical-decision and semantic-categorisation tasks, despite their near-perfect spelling knowledge (e.g., Coltheart, Laxon, Rickard, & Elton, 1988; Jared & Seidenberg, 1991; Starr & Fleming, 2001; Van Orden, 1987; 1991). An extensive overview on this subject is presented in Van Orden, Holden, Podgornik, and Aitchison (1999).

A final example of phonology at work outside the realm of pseudohomophones is provided by results obtained in the first-letter-naming task. In one version of this task, participants are presented with words or word-like letter strings and are requested to name the first *letter* of each stimulus as quickly and as accurately as possible. If the onset of a stimulus is identical to the letter name (e.g., the O in OVER), both beginning and experienced readers name the first letter of these stimuli more quickly than in a condition in which they are not identical (e.g., the O in OTTER). If, however, both beginning and experienced readers are asked to use *phonemes* to identify the first letter in these conditions, the O in OTTER is named faster than the O in OVER (Bosman & de Groot, 1995; Bosman, van Leerdam, & De Gelder, 2000). Thus, in a condition in which the pronunciation of the first letter is phonologically congruent with the onset pronunciation of the stimulus readers are faster than in a condition in which it is incongruent. We believe that this indicates that the phonology of the stimulus is activated while performing first-letter naming, even though it sometimes hinders performance.

Semantics

The third and final factor involved in printed word perception is a word's meaning. Many empirical examples convincingly show the influence of semantic factors on visual word identification. The most widely studied effect is that of semantic-priming, ignited by the seminal paper of Meyer and Schvaneveldt (1971). They showed that participants decided more quickly that two related stimuli (e.g., BREAD and BUTTER) were English words than two unrelated stimuli (e.g., BREAD and DOCTOR).

Two types of word relatedness are distinguished. Semantic relatedness refers to a word pair from the same semantic category (e.g., DOCTOR and NURSE) and associative relatedness refers to word pairs that stem from different semantic

categories (e.g., WINTER and COLD). Reliable priming effects for both types of relatedness exist (for an extensive overview, see Neely, 1991).

Another factor showing the involvement of semantic effects is imageability. Naming latencies of low-frequency low-imageability words (like DOSE or SUAVE) are longer than naming latencies of low-frequency high-imageability words like COMB or PEAR (Cortese, Simpson, & Woolsey, 1997; de Groot, 1989; Strain, Patterson, & Seidenberg, 1995). Likewise, lexical-decision performance on low-imageability words is slower than on high-imageability words, both in the native language and in the second language for more details on the relationship between imageability, concreteness, and context availability (van Hell & de Groot, 1998).

Two final examples of semantic variables affecting visual word perception are semantic ambiguity and semantic synonymy. Words that have several related meanings like SAFE lead to faster lexical decision times than words with unrelated meanings like FAST (Azuma & Van Orden, 1997). Words without clear semantic synonyms like BRIDGE are processed faster in lexical-decision and naming tasks than words with clear semantic synonyms like JAIL, which has PRISON as alternative (Pecher, 2001).

Overview of the present study

Three experiments are presented. The goal of all three is to show what experienced as well as beginning readers do when presented with pseudohomophones. In the first experiment, experienced readers learn to read alternative spellings (pseudohomophones) of low-frequency Dutch words. These alternative spellings differ in one major respect: Half of the spellings deviate slightly from the baseword (have small orthographic changes) and the other half deviate a lot from the baseword (have large orthographic changes). If orthography plays a role, pseudohomophones with a small orthographic change should be learned more quickly than pseudohomophones with a large orthographic change. Furthermore, if phonology and semantics are also involved, pseudohomophones should be read as quickly as their basewords after sufficient presentations.

In the second experiment, both beginning and experienced readers perform a sounds-like-a-word lexical decision task after having read basewords in various frequency conditions. If experimental presentation frequency of basewords affects decisions on pseudohomophones, then phonology and/or semantics are at work in printed word perception (see General Discussion for details). If prior presentation frequency of basewords does not affect decisions on pseudowords then orthography has a negligible effect in this task.

In the third experiment, experienced readers perform a sounds-like-a-word lexical decision on pseudohomophones derived from high-frequency basewords and low-frequency basewords. If baseword frequency affects the decision on pseudohomophones, it suggests that phonology and/or semantics is a crucial factor in printed word perception. Furthermore, if orthographic appearance of pseudohomophones also affects the decision latencies, another demonstration of the role of orthography in reading becomes apparent.

Experiment 1

In this experiment, we investigate the speed with which experienced readers establish new orthographic knowledge and whether the acquisition rate depends upon orthographic complexity.

Method

Participants
A group of 25 Dutch PhD-students of the Department of Psychology of the University of Amsterdam volunteered to participate in the experiment. All participants were native speakers of Dutch.

Materials
Thirty low-frequency Dutch words served as basewords. Each of the basewords was changed into a pseudohomophone. Two sets of pseudohomophones with equal average length (8.5 letters) were created. One set consisted of stimuli with a large orthographic change (mean number of grapheme changes was 3.2, $SD =$ .68), whereas the other set consisted of stimuli with a small orthographic change (mean number of grapheme changes was 2.4, $SD = .51$). This difference in orthographic change was significant, $F(1, 28) = 13.44$, $p < .001$. The stimuli are listed in Appendix A.

Five different training lists and one test list were created. In each training list, six pseudohomophones were not used at all (Frequency 0) six pseudohomophones appeared once (Frequency 1), six pseudohomophones appeared twice (Frequency 2), six pseudohomophones appeared three times (Frequency 3), and six pseudohomophones appeared six times (Frequency 6). Each pseudohomophone appeared in each condition and within each frequency condition, three pseudowords contained a large orthographic change and the remaining three had a small orthographic change. Each training list contained 72 pseudohomophones. The test list contained all 30 pseudohomophones and their corresponding basewords.

Procedure
The experiment was run on a Macintosh computer. The training stimuli were presented on the screen one by one. The participants were told that wrongly spelled words would be presented on the screen, and that they were to read these words as fast and as accurately as possible. Each participant was presented with one of

the training lists. Presentation of the test materials followed the training list immediately. The experimental training stimuli were preceded by 8 pseudohomophone practice trials to familiarise the participants with the task. Naming times were registered with a voice key and a millisecond timer. Each response was evaluated on correctness by the experimenter by pressing a key on the computer keyboard.

Results and discussion

The results of the training stage and the test stage will be discussed separately. Before the data were subjected to statistical analyses, responses based on naming errors (2.9%), errors due to apparatus failure (2.8%), extremely slow (larger than 4000 ms: .1%) and extremely fast responses (less than 250 ms: 0) were removed from the data set.

Training stage

A 2 (orthographic change: large vs. small) × 6 (frequency: 1 vs. 2 vs. 3 vs. 4 vs. 5 vs. 6) ANOVA revealed significant main and interaction effects. The interaction effect between orthographic change and frequency was $F(5, 120) = 5.18$, $p < .001$. The difference in naming times between pseudohomophones with a small orthographic change and pseudohomophones with a large orthographic change was significant in Frequency conditions 1 and 2, $F(1, 24) = 11.78$, $p < .001$, and $F(1, 24) = 4.99$, $p < .05$, respectively. The differences in the other frequency conditions were not significant. The main effect of frequency showed up in both the large and small orthographic change conditions, $F(5, 120) = 47.60$, $p < .001$. The results are depicted in Figure 1.

Test stage

A 2 (stimulus: pseudohomophone vs. baseword) × 5 (frequency: 0 vs. 1 vs. 2 vs. 3 vs. 6) ANOVA on subjects' mean naming times yielded significant main and interaction effects. The interaction effect, $F(4, 96) = 16.84$, $p < .001$, indicated a significant effect of frequency in the pseudohomophone condition, $F(4, 96) = 21.72$, $p < .001$), but not in the baseword condition ($F < 1$). The effect of stimulus was significant in all frequency conditions (main effect: $F(4, 96) = 50.09$, $p < .001$), except in Frequency 6 ($F < 1$). Thus, in all frequency conditions the participants read the basewords faster than the pseudohomophones, but after 6 presentations they read the pseudohomophones as fast as the basewords. The results are presented in Figure 2.

The results of this experiment are clear-cut. Experienced, fluent readers learn alternative spellings of extant low-frequency words in six presentations. The learning curve, however, depends on the complexity of the alternative spelling. Stimuli that deviate more strongly from the baseword (pseudohomophones with a large orthographic change) are learned more slowly than stimuli that deviate less from the baseword (pseudohomophones with a small orthographic change).

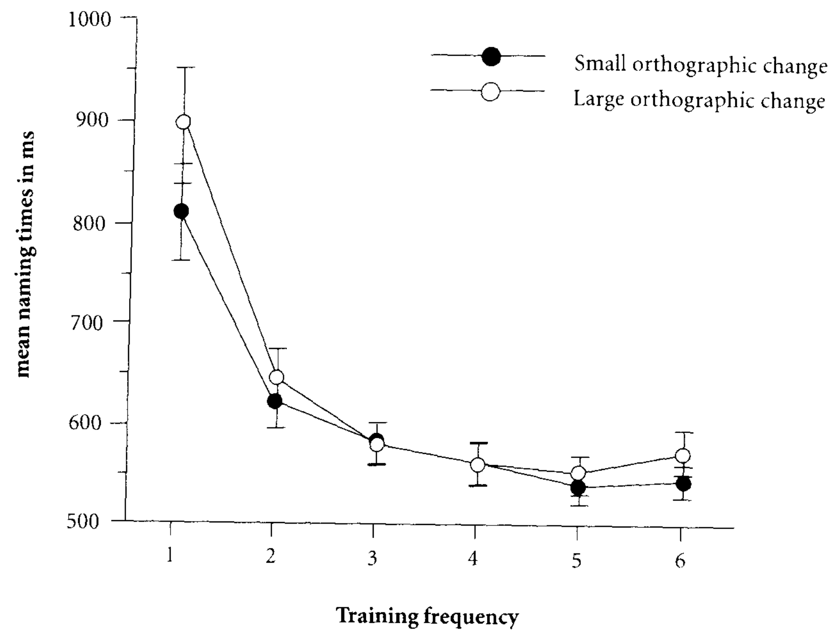

Figure 1. Mean naming times and standard errors of pseudohomophones in the training stage of Experiment 1

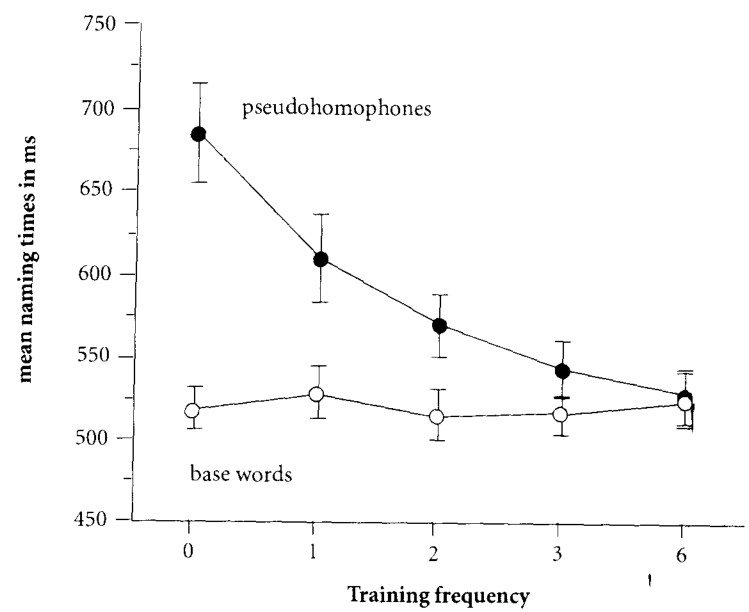

Figure 2. Mean naming times and standard errors of pseudohomophones and basewords in all frequency conditions in the test stage of Experiment 1

Experiment 2

In this experiment, we investigate the effect of reading familiar words on the decision latencies of derived pseudohomophones and pseudowords in beginning and experienced readers.

Method

Participants
From a population of 246 Dutch children of Grade 1, we selected a group of 24 advanced readers (8 boys and 16 girls) with a mean age at the time of testing of 88 months. Their reading level was assessed with the Eén-minuut-test, a standardised reading-decoding test (Caesar, 1975; One-minute test). The score on this test is the number of words read correctly in one minute. The mean score of the children who participated in the experiment was 35.8 ($SD = 1.9$). The mean score of the population was 29.7 ($SD = 10.9$). Twenty students from the Department of Psychology of the University of Amsterdam also participated in the experiment for course credits. These participants did not take part in Experiment 1. All children, referred to as beginning readers, and psychology students, referred to as experienced readers, were native speakers of Dutch.

Materials
A set of 20 monosyllabic basewords, used in the reading stage of the experiment, was selected from the list of Kohnstamm, Schaerlaekens, de Vries, Akkerhuis, and Froonincksx (1981). All words are familiar to six-year old children, but are not used as instruction words in the first three books of the reading course. Ten words consisted of three letters and ten words had four letters. All three-letter words had a CVC-structure (C is consonant, V is vowel). Five of the four-letter words followed a CVVC- and five a CCVC-structure. Four different reading lists were constructed. Each of these lists contained five words that appeared only once (Frequency 1), five words appeared twice (Frequency 2), five words appeared six times (Frequency 6), and five words did not appear at all (Frequency 0). Thus, each baseword occurred in each condition, and each list consisted of 45 basewords. The distribution of the basewords within a list was not random, but such that a word's repetition was evenly distributed over the list, without the order being predictable.

A second list of stimuli was constructed to serve in the decision stage of the experiment. The list consisted of 20 pronounceable pseudohomophones and 20 pseudowords. The pseudohomophones were derived from the basewords of the training list by changing one letter or grapheme. The pseudowords were derived from the pseudohomophones by changing one letter or grapheme. The spelling of the pseudowords was orthographically legal, but the phonology was dissimilar from extant words, whereas the spelling of the pseudohomophones was also orthographically legal, but their phonology was identical to extant words. Appendix B lists the set of basewords, pseudohomophones, and pseudowords.

Procedure
The experiment was run on a Macintosh computer. All participants (both beginning and experienced readers) were presented with one of the four reading lists. They were asked to read aloud the words of the list as quickly and as accurately as possible. Naming times were registered with a voice key and a millisecond timer. Each response was evaluated on correctness by the experimenter by pressing a key on the computer keyboard. Before the experimental session started each participant received five practice trials.

In the second part of the experiment, participants were confronted with the decision list. They were told that letter strings would appear on the screen, but that none of the words as such exists according to the way they were spelled. The participants were asked to decide as quickly and as accurately as possible whether the word if pronounced was a Dutch word (yes) or not (no) by pressing the proper button. A millisecond timer registered the time it took the participants to make the decision.

Results and discussion

The results of the beginning and experienced readers will be analysed separately but discussed simultaneously. The results of the beginning readers, the children (CH) will be presented first, followed by those of the experienced readers, the adults (AD).

Reading stage
Before the data were subjected to analysis responses based on naming errors (CH: .9%, AD: .3%), errors due to apparatus failure (CH: 7.2%, AD: 1.4%), extremely slow (more than three standard deviations above the mean; CH: 1.8%, AD: .6%) and extremely fast responses (less than 250 ms, CH: 0%, AD: .3%) were removed from the data set. A 6 (exposure: 1, 2, 3, 4, 5, 6) ANOVA was performed on the data of the beginning and the adult readers separately. The main effect of exposure was significant for both the beginning and the experienced readers, CH: $F(5, 115) = 6.51$, $p < .001$; AD: $F(5, 95) = 2.32$, $p < .05$. A post-hoc analysis (Newman-Keuls, $p < .01$) on the data of the beginning readers revealed that the mean of 1st Exposure (813 ms) was significantly lower than those of 3rd Exposure (717 ms), 4th Exposure (711 ms), 5th Exposure (707 ms), and 6th Exposure (735 ms). The 1st Exposure (813 ms) did not differ significantly from the 2nd Exposure (769 ms).

Further exploration of the data of the experienced readers showed a significant difference between Frequency 1 and 6, $F(1, 19) = 4.73$, $p < .05$. The mean naming times of Frequencies 1 to 6 were 447, 447, 445, 437, 441, and 435 ms respectively. Thus, both beginning and experienced readers showed a frequency effect.

Table 1. Mean decision latencies of the beginning and experienced readers in the decision stage of Experiment 2

	Pseudohomophones[1]		Pseudowords[2]	
Baseword frequency	Beginning	Experienced	Beginning	Experienced
0	2478 (112)	739 (28)	3007 (213)	975 (60)
1	2323 (126)	675 (23)	3112 (203)	938 (50)
2	2388 (166)	671 (19)	2971 (182)	924 (44)
6	2186 (109)	681 (23)	3031 (181)	926 (45)
Total	2343 (106)	691 (20)	3030 (176)	941 (46)

[1] Yes-response required, [2] No-response required. Standard errors in parentheses.

Decision stage
Before the data were analysed, decision errors (CH: 6.4%, AD: 6.0%), extremely slow (more than three standard deviations above the mean; CH: 1.9%, AD: .8%) and extremely fast responses (less than 250 ms, CH: 0%, AD: 0%) were removed from the data set. Both the beginning and the experienced readers were faster responding yes to pseudohomophones than responding no to pseudowords, CH: $F(1, 47) = 26.71$, $p < .001$; AD: $F(1, 39) = 47.66$, $p < .001$. The number of errors made on the two types of stimuli did not differ significantly from each other in both groups, both F's < 1. The results are presented in Table 1.

An analysis on the decision times for pseudohomophones for the beginning readers with reading frequency as within factor showed no significant effect, CH: $F(3, 69) = 2.02$, $p = .12$. A planned contrast between mean decision times of Frequency 0 and Frequency 6 revealed a significant decrease, CH: $F(1, 23) = 12.93$, $p < .001$. Pseudohomophones of which the basewords were read 6 times in the preceding reading stage were decided on faster than pseudohomophones of which the basewords were not read at all in the reading stage. No significant effects emerged in the same analyses on the mean correct no-response latencies of the pseudowords, $F < 1$.

The same analysis for the group of experienced readers revealed a significant effect of reading frequency, AD: $F(3, 57) = 4.32$, $p < .01$. A post-hoc analysis on the means for the experienced readers showed that decision times of pseudohomophones in Frequency 0 were significantly longer (Newman-Keuls, $p < .05$) than those of Frequency 1, Frequency 2 and Frequency 6. Pseudohomophones derived of basewords that were not read in the reading stage showed longer decision latencies than pseudohomophones that were read at least once in the reading stage. Again, no significant effects emerged in the same analyses on the mean correct no-response latencies of the pseudowords, $F(3, 57) = 1.22$, $p = .31$.

The results of the reading stage revealed that both beginning and experienced readers read highly familiar words more quickly after several presentations. The effect of repetition is obvious. The drop in reading time occurred in the beginning readers after the third presentation, whereas the drop in the reading time of the experienced readers occurred after six presentations.

Yes-decisions (i.e., to pseudohomophones) were faster than no-decisions (i.e., to pseudowords) in both beginning and experienced readers. This converges with most other research. Yes-responses are usually faster than no-responses.

More interestingly is that both beginning and experienced readers decide more quickly that a pseudohomophone sounds like a word when the corresponding basewords has been presented more often in a preceding reading stage. The no-decisions on the pseudowords of both the beginning and the experienced readers were not affected by the frequency of the corresponding baseword.

Experiment 3

In this experiment, we investigate the effect of baseword frequency and orthographic change on processing pseudohomophones and pseudowords in experienced readers.

Method

Participants
Twenty first-year students of the Department of Psychology of the University of Amsterdam participated in the experiment, fulfilling course requirements. They were native speakers of Dutch and had not participated in Experiments 1 and 2.

Materials
The set of 80 stimuli consisted of 40 pseudohomophones and 40 pseudowords. The pseudohomophones were constructed by changing one letter or letter cluster of the baseword into one that represents the same phoneme, or by leaving out a silent letter (i.e., h). The changes were, t-d, ei-ij, ou-au, ch-g, h-Ø. Half of the pseudohomophones were derived from high-frequency basewords (equal to or greater than 52 and smaller than or equal to 1446 occurrences per million; Uit den Boogaart, 1975). The other half were derived from low-frequency basewords (equal to or greater than 4 and smaller than or equal to 18 occurrences per million). The difference in mean frequencies between the two groups was significant, $F(1,38) = 12.72$, $p < .001$. The pseudohomophones were also matched on length: Half of the high-frequency pseudohomophones and half of the low-frequency pseudohomophones contained four letters, and the remaining halves had five letters.

The set of pseudowords was developed according to Dutch rules of orthography. The construction of the pseudowords was such that 20 of them had a high (equal to or greater than 144 and smaller than or equal to 2741) Cumulative Positional Trigram frequency (CPT-frequency) and the other half a low CPT-frequency (equal to or greater than 0 and smaller than or equal to 48). The CPT-

frequency (Rolf & van Rijnsoever, 1984) is a standard for the incidence of a particular combination of letters. A high CPT-frequency indicates that the sum of frequencies of trigrams occurs relatively often in Dutch orthography. A low CPT-frequency indicates that its occurrence is less likely. The difference in CPT-frequency between the two groups was significant, $F(1,38) = 18.19$, $p < .001$. The pseudowords were also matched on length. The stimuli used in this experiment are presented in Appendix C.

Procedure
The experiment was run on a Macintosh computer. Each participant received the list of stimuli in a different random order. They were told that words would appear on the screen, but none of the words as such existed according to the way they were spelled. Half of the words when pronounced according to Dutch grapheme-phoneme correspondence rules actually sound like a Dutch word but the other half of the words do not. The participants were asked to decide as quickly and as accurately as possible whether the word when pronounced was a Dutch word (yes) or not (no) by pressing the proper button. A millisecond timer registered the time it took the participants to make the decision.

Results and discussion

Before the data were subjected to analysis, erroneous responses (5.6%), extremely long responses (more than 3 standard deviations above the mean; .8%), and extremely short responses (< 250 ms; 0) were removed from the data set.

A 2 (type of stimulus: pseudohomophones vs. pseudowords) × 2 (length: 4 vs. 5) × 2 (frequency: high vs. low) ANOVA on subjects' mean response latencies showed a significant main effect of type of stimulus, $F(1,19) = 42.67$, $p < .001$. Mean yes-response latencies to pseudohomophones ($M = 782$ ms; $SD = 158$) were shorter than mean no-response latencies to pseudowords ($M = 1091$ ms; $SD = 359$). The same analysis on the mean number of errors showed a significant difference, $F(1,19) = 6.37$, $p < .05$. The mean number of errors to pseudohomophones ($M = .14$, $SD = .07$) was larger than to pseudowords ($M = .09$, $SD = .06$). Thus, it took the participants longer to say no to the pseudowords than yes to pseudohomophones, but they made fewer errors on pseudowords than on pseudohomophones.

A significant three-way interaction emerged between type of stimulus, length, and frequency on both the mean response latencies and mean number of errors, $Fv1,19) = 5.60$, $p < .05$, and $F(1,19) = 4.76$, $p < .05$, respectively. For the sake of clarity, the subsequent analyses of the data on pseudohomophones and pseudowords will be discussed separately.

Pseudoword no-decisions
A 2 (length: 4 vs. 5) × 2 (CPT-frequency: high vs. low) ANOVA on subjects' mean latencies and on subject's mean number of errors showed no significant main or interaction effects.

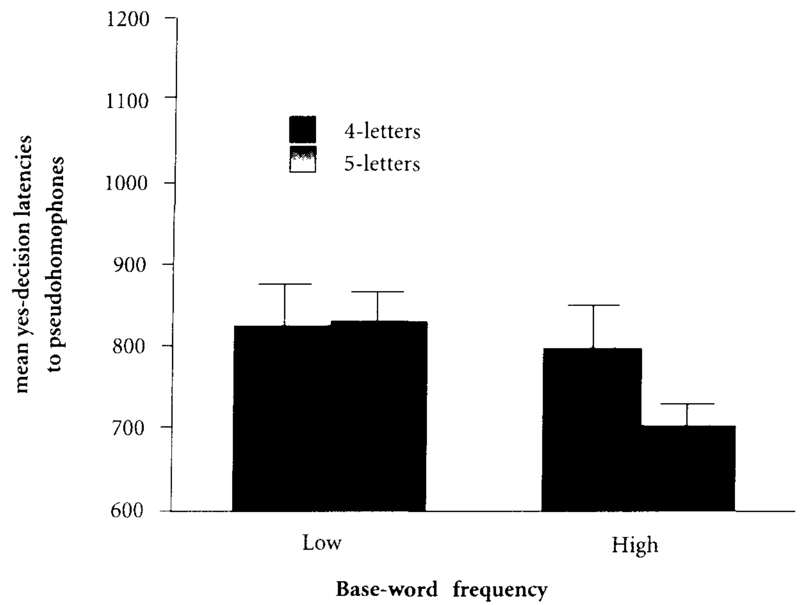

Figure 3. Mean yes-response latencies and standard errors of pseudohomophones in Experiment 3

Pseudohomophone yes-decisions
A 2 (length: 4 vs. 5) × 2 (frequency: high vs. low) ANOVA on subjects' mean latencies revealed a significant interaction effect, $F(1,19) = 6.47$, $p < .05$. The frequency effect appeared to be significant in the 5–letter condition only, $F(1,19) = 25.25$, $p < .001$. The length effect was significant in the high-frequency condition only, $F(1,19) = 19.55$, $p < .001$.

The same analysis on mean number of errors revealed a similar pattern. The interaction effect between length and frequency did not reach significance, $F(1,19) = 2.44$, $p = .14$. Further analyses showed that the frequency effect was only significant in the 5-letter condition, $F(1,19) = 13.75$, $p < .001$. The effect of length was again only significant in the high-frequency condition, $F(1,19) = 1.88$, $p < .01$. The results are depicted in Figure 3.

As in Experiment 2, participants decided more quickly that pseudohomophones sound like words than that pseudowords do not sound like words. Unlike the results of Experiment 2, participants made more errors on pseudohomophones (incorrectly deciding that they do not sound like words) than on pseudowords (incorrectly deciding that they sound like words).

Pseudoword-decision times were not affected by length or by CPT-frequency. Stated differently, the no-decisions do not appear to be affected by otherwise relevant orthographic characteristics. Pseudohomophone-decision times, on the other hand, are affected by orthographic properties of word (i.e., length and baseword

frequency). Pseudohomophones derived from high-frequency basewords are accepted more quickly than pseudohomophones derived from low-frequency basewords. Words that are more familiar (semantically, orthographically, and/or phonologically?) facilitate the processing of pseudohomophones. Thus, it seems that in this experimental set-up semantics (and phonology) overrules orthography.

However, the fact that length affected the decision times of the pseudohomophones suggests that orthography also plays a role. Participants decided more quickly that long pseudohomophones (i.e., five letters) sounded like words than short pseudohomophones (i.e., four letters). This is an interesting result, because, generally, shorter stimuli are processed more quickly. The reason that pseudohomophones with five letters are processed more quickly is probably because their appearance deviated only 20% from the baseword, whereas the pseudohomophones with four letters changed 25% of their appearance.[1]

General discussion

Changing orthographic appearance and maintaining the phonology of words elicits a rather quick and flexible adjustment process in the behaviour of experienced readers. In the first experiment, experienced readers learned to read pseudohomophone spellings of extant words in six presentations. The flexibility of the adjustment process was demonstrated by the finding that pseudohomophones that deviated orthographically more from the original basewords were a little harder to learn to read than pseudohomophones that deviated less. Orthography also played a role: Pseudohomophones more similar to the baseword were accepted more quickly than pseudohomophones less similar to the baseword.

Baseword frequency, irrespective of whether this was induced experimentally (via repeated exposure) or derived from natural occurrence (high frequency of occurrence in language), affected pseudohomophone processing, but did not affect pseudoword processing. Beginning and experienced readers responded more quickly to pseudohomophones derived from high-frequency basewords than to pseudohomophones derived from low-frequency basewords. This result converges with other findings of English-speaking and French-speaking participants (Borowsky & Masson, 1999; Grainger et al., 2000; Marmurek & Kwantes, 1996; Taft & Russell, 1992; Van Orden, 1991; Van Orden et al., 1992; see for null-findings Herdman, LeFevre, & Greenham, 1996; McCann & Besner, 1987).

An interesting and hotly debated issue is the explanation of the (baseword)-frequency effect (see Monsell, 1991 for an excellent discussion of this topic). There is good reason to believe that frequency effects are at least partly reflecting meaning-related aspects. Standard frequency effects are often much stronger in lexical decision than in naming and Monsell (1991) reports the results of a semantic-categorisation experiment in which he finds robust and strong frequency effects. Both lexical decision and semantic categorisation involve semantics.

Frequency effects may also be attributed to the phonologic aspect (and maybe even to the orthographic aspect) of words. Although we are not aware of a study in which this was investigated, repeated readings of pseudowords must in the end lead to faster reading times (i.e., cause a frequency effect) despite the absence of semantics. Whether we would have to attribute this effect to the orthographic or phonologic aspect is difficult to ascertain and can only be addressed within the theoretical standpoint one has taken.

Theorists, however, do not need to put themselves in this awkward position if they are willing to give up the search for causal components in human cognitive architecture. An alternative account, in which effects are interpreted as the results of interactive dynamics between three aspects that seem to govern reading, circumvents the problem of relating an effect to a particular cognitive process, representation, or strategy (see Van Orden & Paap, 1997; Van Orden et al., 1999).

An attractive alternative, but by no means the only solution, is the phonologic coherence model, a recurrent-network account. The reason for using Van Orden's account is twofold. First, his proposal not only assumes that orthography, phonology, as well as semantics contribute to the processes involved in printed word perception, but also explicitly describes (and models, Farrar & Van Orden, 2001) how these aspects interact. That is, the phonologic coherence model is an account in which input and output form an irreducible interdependent whole. Uni-directional causality is given up for bi-directional causality. This implication of the account solves the problem encountered when applying traditional causality theory, in which we are forced to attribute an empirical phenomenon to one particular aspect or process.

Second, the account is a metaphor. Generally, theorists consider nodes in a network to be mental, symbolic representations. This notion is abandoned in Van Orden's network model. Nodes are not psychologically real units of cognition. Their explanatory power resides in the dynamics of the model and should not be attributed causal properties outside of these dynamics. In fact, nodes serve a narrative function only; they are pragmatic notations for modelling or illustration purposes.

The remainder of this chapter is devoted to a severely abridged description of the model. More detailed information on the account is presented in several publications by Van Orden and others (1990, 1994, and 1997, in press). Figure 4 summarises the description presented below.

Three families of fully interdependent nodes (i.e., orthographic nodes, phonologic nodes, and semantic nodes) are sufficient to describe reading and spelling performance in a large variety of laboratory reading tasks, for example the notorious frequency by regularity or consistency interaction (Seidenberg, Waters, Barnes & Tanenhaus, 1984) and the counterintuitive feedback consistency effect (Stone et al., 1997), and it explains natural reading and spelling phenomena, for example, why spelling is more difficult than reading (Bosman & Van Orden, 1997).

An essential aspect of the model is that all node families are connected recurrently or bi-directionally (Note the relation with the assumption of bi-directional causality). That is, there is a connection from each of the orthographic nodes to

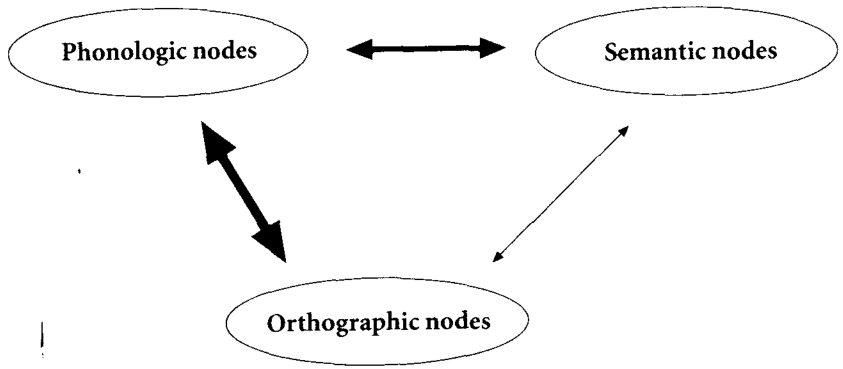

Figure 4. Macro dynamics in the phonologic coherence model

each of the phonologic and each of the semantic nodes, but there are also backward connections from each of the phonologic and semantic nodes to the orthographic nodes, and similarly so for the connections between phonologic and semantic nodes. This is represented in Figure 4 by the double arrows between all three node families.

Upon presentation of a printed word the orthographic nodes get activated, which in turn activate phonologic and semantic nodes (feedforward activation). The recurrent connections cause the phonologic and semantic nodes to activate the orthographic nodes again (feedback activation). Whenever the feedback activation pattern matches the feedforward activation pattern, a temporarily stable, coherent dynamic whole emerges.

It is important to note that the overall strength between node families differ, as illustrated by the relative boldness of the arrows. Connection strength indicates the speed with which dynamics cohere. In the present case, the connections between orthographic and phonologic nodes are strongest. In alphabetic languages, letters and phonemes correlate rather strongly. The letter P is almost always pronounced as /p/ (exceptions are the P in PHOENIX or PSYCHO), and the phoneme /p/ is almost always written with a P.

The relations between phonemes and semantics are less strong. Knowing that a word starts with the phoneme P does not provide us with a lot of information on its meaning (e.g., PAGE, PURE, or PRACTICAL do not share a lot of meaning). Although phonologic and semantic nodes share weak connections, they are stronger than those between semantic and orthographic nodes. This is primarily because we learned to speak before we learn to read, and we speak more often than we read.

Thus, this recurrent network predicts that dynamics involving the relation between orthography and phonology cohere before the dynamics between phonology and semantics, which, in turn, cohere before the dynamics between semantics and orthography. If this is true, it should not surprise us that phonology is an early and omnipresent constraint in printed word perception. Numerous findings demonstrate the validity of this assumption of the model. Recurrent feedback or reciprocal constraints on the relation between orthography and phonology are presented by Stone, Vanhoy, and Van Orden (1997) for English and by Ziegler, Montant, and Jacobs (1997) for French (see Peereman, Content & Bonin, 1998 for null-findings in French).

A recurrent network is, simply put, a system that is designed to detect the statistical relationships present in the stimulus.[2] A learned network favours consistent relations above inconsistent ones. Thus, words with consistent spellings (e.g., RAT or SAVE) are generally read more quickly than words with inconsistent spellings (e.g., CHOIR or PINT). The network (and the reader alike) can overcome slow processing of inconsistent words (e.g., HAVE) through frequent presentations. In Experiments 1 and 3, we showed a) an effect of orthographic change on printed word perception and b) an effect of presentation frequency. Pseudohomophones with less common orthographic-phonologic relations were read slightly slower than those with more common relations between orthography and phonology. In the first experiment readers overcame the fairly uncommon (irregular) spellings of the pseudohomophones after only six presentations.

The semantic aspect became apparent, at least partly, in the final experiment. Pseudohomophones derived from high-frequency basewords were processed more quickly than pseudohomophones derived from low-frequency basewords. In terms of the model, semantic-phonologic dynamics and probably also semantic-orthographic dynamics cohere more quickly when presented with "high-frequency" pseudohomophones than with "low-frequency" pseudohomophones. A similar explanation holds for the findings with experimentally manipulated baseword frequency in Experiment 2.

Thus, the results of the above-presented experiments suggest interdependent roles for orthography, phonology, and semantics in the reading behaviour of beginning and experienced readers. The results can be explained in terms of the phonologic coherence model and complement other (better) empirical examples of the interdependence between orthography, phonology, and semantics presented in, for example, Farrar, Van Orden, and Hamouz (2001), Vanhoy and Van Orden (2001), and in Gottlob, Goldinger, Stone, and Van Orden (1999).

This very short description of the phonologic coherence model was meant to demonstrate that effects found in experiments need not be (in fact, *cannot be*) attributed to a single cause. They are better understood as emergent properties in a highly interactive, interdependent, dynamical system.

Appendix A. Stimuli used in Experiment 1

Baseword	Pseudohomophone	Letters	Changes	Orthographic Change
lacherig	laggurich	9	3	large
nauwelijks	nouwuluks	9	3	large
tijdelijk	teiduluk	8	3	large
dagelijks	dachuluks	9	3	large
houterig	hauturich	9	3	large
vrouwelijk	vraueluk	8	3	large
veiligheid	vijlichhijt	9	4	large
mogelijk	moochuluk	9	4	large
schrijven	sgreivun	8	3	large
vijandig	veiandich	9	2	large
lichtelijk	ligtuluk	8	3	large
brouwsels	brausuls	8	3	large
godsvrucht	gotsvrugd	9	3	large
onmiddellijk	omiduluk	8	5	large
eigenschap	ijgunsgap	8	3	large
drijfhout	dreifhaud	9	3	small
schildpad	sgiltpat	8	3	small
kwaadheid	kwaathijt	8	3	small
rijstbouw	reisdbauw	9	3	small
slechtheid	slegthijt	8	3	small
damschijf	damsgeif	8	2	small
beschijnen	besgeinen	9	2	small
schaakbord	sgaakbort	9	2	small
dwaasheid	dwaashijt	8	2	small
achtvoudig	agtvaudig	9	2	small
schrijnend	sgreinent	9	3	small
landschap	lantsgap	8	2	small
slagveld	slachvelt	9	2	small
achterlijf	agterleif	9	2	small
koudvuur	kautvuur	8	2	small

Appendix B. Stimuli used in Experiment 2

Baseword	Pseudohomophone	Pseudoword
kous	kaus	kaul
vijf	veif	veim
rijd	reid	reif
god	got	gof
kwijt	kweit	kweis
wijs	weis	weil
geit	gijt	gijm
bed	bet	bem
fout	faut	faus
stad	stat	stas
prijs	preis	preil
vouw	vauw	vauk

Appendix B. (*cont.*)

Baseword	Pseudohomophone	Pseudoword
tijd	teid	tein
bad	bat	baf
pijn	pein	peim
lijm	leim	leil
glad	glat	glap
hoed	hoet	hoel
grijs	greis	greik
rijm	reim	reil

Appendix C. Stimuli used in Experiment 3

Baseword	Pseudohomophone	Baseword Frequency	Pseudoword	CPT-frequency
goed	goet	1446	bijns	2741
groot	grood	1296	ficht	1363
vrouw	vrauw	585	wocht	1291
weg	wech	492	techt	1261
klein	klijn	484	zerd	1171
woord	woort	357	vroud	1113
juist	juisd	298	vant	750
kort	kord	240	plijfd	550
vrij	vrei	239	keeg	504
slecht	slegt	144	krous	496
thuis	tuis	144	megt	466
zwart	zward	143	bist	266
recht	regt	121	peids	258
prijs	preis	117	kest	226
kracht	kragt	97	beisd	219
breed	breet	64	rebt	188
fijn	fein	62	sleig	163
fout	faut	58	deit	152
paus	pous	53	glopt	145
grijs	greis	52	treid	144
joods	joots	18	krugd	140
knecht	knegt	17	bloch	130
touw	tauw	17	densd	120
spijt	speit	15	slad	104
grauw	grouw	15	slout	88
vaart	vaard	15	flijp	79
pand	pant	13	grech	73
blijk	bleik	12	gauf	63
plicht	pligt	12	praul	55
klauw	klouw	11	zweis	42
saus	sous	11	drad	20
plein	plijn	10	pach	18
zuid	zuit	10	daafd	13
jacht	jagt	10	mous	11

Appendix C. *(cont.)*

Baseword	Pseudohomophone	Baseword Frequency	Pseudoword	CPT-frequency
trant	trand	9	flund	11
dag	dach	8	jots	3
geit	geid	8	taun	0
wreed	wreet	8	teif	0
brein	brijn	5	zauk	0
wijf	weif	4	wreg	0

Notes

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1. A post-hoc analysis of the difference in orthographic similarity, a measure developed by Van Orden (1987) and derived from Weber's measure of graphic similarity (1970), showed that pseudohomophones with four letters were significantly less similar to their basewords (.66) than pseudohomophones with five letters (.72), $F(1,38) = 11.22$, $p < .002$.

2. Feedforward networks, pattern-associators, and simple recurrent networks also pick up the statistical regularities present in the stimulus (see for example, Mcleod, Plunkett & Rolls, 1998).

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